A Simulation Module for a Regulating Power Market

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by

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Certificate

It is certified that the work contained in this thesis entitled **A SIMULATION MODULE FOR A REGULATING POWER MARKET** by *A Krishna Kumar* has been carried out under the joint supervision of Prof.Dr.-Ing. Jürgen Stenzel, Technische Universitat Darmstadt, Germany and myself. This work has not been submitted elsewhere for a degree.

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Evaluation of the Master Thesis

A Simulation Module for a Regulation Market

Under my supervision and the guidance of Dipl.-Ing. Kristján Halldórsson Mr. Anaparthi prepared his thesis. After being introduced to the subject he worked independently and he was very diligent. In the first phase of his work he explored the main regulation markets in Europe. In the second phase he designed a simulation module for a regulation market based on the exploration. In the third phase he tested an implementation of the module with positive results. Considering the various aspects of his thesis (research work, results, written thesis and presentation) my evaluation leads to the mark very good.

(German marks: 1: very good, 2: good, 3: satisfactory, 4: sufficient, 5: unsatisfactory)

Darmstadt 14.2.2002

J. Stenzel

(Prof. Dr.-Ing. Jürgen Stenzel)

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Abstract

In recent past, the power industries, all around the world, are undergoing major restructuring leading to deregulated electricity market. This aims at introducing competition among various market participants and bringing several competitive opportunities. In a competitive electricity market, an Independent System Operator (ISO) is responsible for system administration to meet the market contracts and in addition to supply the regulating power arising out of the imbalances between actual generation and demand. For supply of regulating power, special markets are set up which are similar to the spot markets but with different time limits and different set of power providers.

In this work, a model is proposed that brings the relationship between the regulating market, the net operator, the regulating generators and other participants. The regulating market considered is an hour-to-hour exchange market, which maintains the balance between generation and demand. Different existing markets in Europe have been analysed and compared to create a basis for the design and implementation of a simulation module for the regulating market model. The proposed model is then tested for the power markets of Norway, Sweden and Finland. The simulation model presented in this work forms a basis for calculating the regulating price and allocating volume of regulating power to the generators participating in the regulating market.

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ABBREVIATIONS

APX	:	Amsterdam Power Exchnage
BDI	:	Bundesverband der Deutsche Industrie
BGM	:	Balancing Group Managers
BM	:	Balancing Mechanism
BNFL	:	British Nuclear Fuels Limited
BP	:	Balancing Period
BSC	:	Balancing and Settlement Code
BSC Co	:	Balancing and Settlement Code Company
CEGB	:	Central Electricity Generating Board
DF	:	Demand Forecaster
DVG	:	Deutsche Verbundgesellschaft
EEX	:	European Power Exchnage
EMA	:	Energy Market Authority
ETSO	:	European Transmission System Operators
FPN	:	Final Physical Notifications
$GENS_{REG}$	:	Regulating generators
LPX	:	Leipzig Power Exchnage
MCP	:	Market Clearing Price
MEL	:	Maximum Export Limit
NETA	:	New electricity trading arrangements
NGC	:	National Grid Company
NORDEL	:	the Nordic TSOs
NVE	:	The Norwegian Water Resources and Energy Directorate
OTC	:	Over the Counter
PN	:	Physical Notifications
PPP	:	Pool Purchase Price
PSP	:	Pool Selling Price
RSBs	:	Regulating Supply Bids
SMP	:	System Marginal Price

SO	:	System Operator
SRM	:	Simulation Module for Regulating market
SSA	:	System Security Analysis
SVCs	:	Stativ Var Compensators
SvK	:	Svenska Kraftnät
TSOI	:	Association of TSOs in Ireland
TSOs	:	Transmission System Operators
UCTE	:	The Union for the Co-ordination of Transmission of Electricity
UK	:	United Kingdom
UKTSOA	:	The United Kingdom TSO association
VDEW	:	Vereinigung Deutscher Elektrizitätswerke
VIK	:	Verband der Industriellen Energie- und Kraftwirtschaft

Chapter 1

INTRODUCTION

Towards the end of twentieth century, many electric utilities and power network companies, worldwide have changed from vertically integrated structure to open market systems. The main focus has been to provide customers with electricity at lower prices, to offer them a greater choice in purchasing energy at economical price and enhance the power system performance. This paved a way to a deregulated power system, in which rules are re-regulated to bring competition among various market participants like power generators, power consumers and bulk power marketers. The System Operator (SO) or net operator and power brokers participate in the facilitation of the market.

Deregulation of the electric power system led to the unbundling of the vertically integrated system, in which all the activities of the electric industries were dominated by large utilities, into separate entities responsible for generation, transmission, distribution and market administration. Power generation and distribution are made competitive while transmission is still taken as a regulated, monopoly franchise business. An Independent System Operator (ISO), which performs its functions independently and indiscriminately, organises the operation of the grid and the transmission network that ensures the reliability and security along with the economic operation of the entire system.

Different power markets are set up for power transactions in a deregulated market. These are the Bilateral markets (open access), Pool markets and the Power exchange markets. In bilateral contract markets, bulk of the energy transactions are carried out as bilateral trades between power generators and bulk consumers/distributors directly where the role of ISO is limited only to system security management, congestion management and reliability aspects. In a power pool, the ISO is responsible for carrying out all the market activities in which all the energy transactions are carried out through the pool organized in a spot market. In a power exchange, the buyers can bid for their demands along with their willingness to pay. Apart from these power markets, the ISO is responsible for minute-to-minute balance between production and consumption in its area.

To perform this task, a *regulating market* (balance market) is established which comprises of balance adjustment, balance regulation and balance settlement.

The power trading company, which serves the roles of electricity supplier and/or balance provider, either takes the balance responsibility itself or purchases this service from another company. It purchases power through power exchange or directly from an electricity producer/another trading company. The balance provider will have to pay for power (balance power) sufficient to restore the balance between generation and load. All these tasks are done by the SO which ensures that production/imports correspond to consumption/exports and that the electricity system's plants work together in an operationally reliable way.

In a deregulated market the balance responsibility maintains the control tasks of *primary* and *secondary regulation*. This means that the balance provider or balancing group is also financially responsible for the production and consumption of power always being in balance within the supplier's commitment. Hence it has to provide (pay for) the sufficient *regulating power*. *Primary* regulation means that the physical balance of the electricity system is finely adjusted by means of the level of production in a number of power plants being automatically increased or decreased.

Primary regulation provides *Automatic Regulating Power* through the turbines in certain power stations (e.g. large hydro-power stations) that are equipped with special regulators for this purpose. This is exchanged with participants who report their regulation capability to the balance service. *Secondary regulation* reduces any imbalance in the national electricity system through manual upward and downward regulation of so called regulation objects and it fine-tunes the final balance of power. It is achieved through power deals with the balance administrators who have entered into agreements with the system operator with regard to participating in balance regulation. [10]

It is found in the literature that the regulating markets play an important role in the balancing mechanism of the deregulated power system. This requires a separate market to be set up for the regulating markets. In a competitive electricity market, the supply of regulating power is separated from the actual tasks of the net operator and special markets are set up for these purposes which are similar to the spot markets but with different time limits and different set of

power providers. The regulating markets already adopted in various countries have different structure and price settlement mechanisms. Hence, in this work, a model has been proposed that brings the relationship between the regulating market, the net operator, the regulating generators and the other participants of the regulating market. For developing the simulation model, the different existing markets in Europe have been analysed first and compared to create a basis for the design and implementation of the simulation module required for the regulating market. Later, a generic module is designed that simulates the various regulating markets of Europe.

The work reported in this thesis has been organized into five chapters. The present chapter introduces the general concepts of deregulation of electricity market and the need for regulating power and sets the motivation behind the present work.

Chapter 2 discusses the technical aspects behind power balancing that are required for the proper functioning of the electricity market.

Chapter 3 studies and analyses various electricity markets in Europe along with how regulation is achieved in each of the different scenarios. The markets that have been analyzed are of the Scandinavian countries i.e. of Norway, Sweden and Finland, United Kingdom and Germany. The main focus has been to study the regulating market structure of each of these countries and the associated time rules and time points.

In Chapter 4, a generic simulation model for the regulating power market to balance power generation and consumption is presented which has been developed based on the different regulating markets in Europe. This chapter presents requirements analysis for the model, system design using object-oriented modeling and testing of the model for some sampled data.

Finally, Chapter 5 brings out the conclusions obtained from testing of the model and its implementation. The main findings of the research work carried out have been presented and few areas of further research have been identified.

Chapter 2

TECHNICAL ASPECTS BEHIND THE POWER BALANCING

The Union for the Co-ordination of Transmission of Electricity (UCTE) network covers the major part of continental Europe and co-ordinates the interests of *Transmission System Operators* (TSOs) in twenty European countries. The United Kingdom TSO association (UKTSOA), the Nordic TSOs (NORDEL) and the association of TSOs in Ireland (TSOI), who are together known as European Transmission System Operators (ETSO) work in close co-ordination with UCTE and are responsible for operation in their own control areas. The requirements of applying the technical aspects of power balancing are therefore provided by UCTE to maintain a strong synchronous interconnected network. Within a given control area, load demand should be covered at all times by electricity produced in that area, together with electricity imports (under purchase contracts and/or electricity production from jointly operated plants outside the zone concerned). In order to maintain this balance, reserve generating capacity should be available to cover power plant outages and any disturbances affecting generation, demand and transmission [2].

Where demand exceeds generation on a continuous basis, notwithstanding the availability of this reserve capacity, immediate action must be taken to restore the balance between the two (by the use of standby supplies, contractual load variation or load shedding or the shedding of a proportion of customer load as a last resort). Sufficient transmission capacity must be maintained at all times to accommodate reserve control capacity and standby supplies. In addition to these factors, which are directly associated with generation, account must also be taken of system conditions, given that network constraints may reduce scope for the transmission of power produced [2]. If generation and demand are not equal, the system frequency rapidly increases or decreases, which is only acceptable within a very tight bandwidth around the nominal frequency of 50 Hz in Europe. Therefore, power balancing includes the task of frequency control and is therefore discussed below.

2.1 FREQUENCY VALUE

In UCTE, under undisturbed conditions, the network frequency is maintained within strict limits in order to ensure the full and rapid deployment of control facilities in response to a disturbance. Outside periods for the correction of synchronous time, the set point frequency is 50 Hz. Three types of operating conditions are considered: where the deviation $|\Delta f|$ between the instantaneous frequency and the set point frequency is

- equal to or less than 50 mHz, operating conditions are considered as normal,
- greater than 50 mHz but less than 150 mHz, operating conditions are deemed to be impaired, but with no major risk, provided that control facilities in the affected areas are ready for deployment;
- greater than 150 mHz, operating conditions are deemed to be severely impaired, because there are significant risks of the malfunction of the interconnected network.

Even in case of a major frequency deviation, each control area maintains its interconnections with adjoining areas, provided that the secure operation of its own system is not jeopardised. Frequency thresholds are also defined for load shedding. The UCTE recommends that its members should initiate the first stage of automatic load shedding in response to a frequency threshold no lower than 49 Hz [3].

Also in a synchronously interconnected transmission system, a power surplus or deficit in one part of the system inevitably affects the whole system because frequency is always uniform in the complete interconnection. So short-term balancing with activation times of seconds or minutes has to be performed more or less automatically. Short-term balancing is composed of three levels a very fast decentralised automatic frequency control in some of the power plants (*primary control*), a centralised automatic load-frequency control in each TSO's control centre (*secondary control*), and the manual activation of additional short-term reserves, also co-ordinated in the control centres as described in the next sections.

2.2 PRIMARY CONTROL

Primary control involves the action of turbine speed governors in generating units, which wil respond when the frequency deviates from the synchronous frequency (set point value) as a resul of an imbalance between generation and demand in the synchronously interconnected network a

a whole. The primary control maintained by each control area gets activated within 30 seconds for any imbalance in power. Technical solidarity between members will involve the simultaneous action of primary control on all generating units involved in system control [3].

The various assumptions, characteristics and parameters applied to primary control are as follows:

- The *maximum instantaneous deviation* (DP) between generation and demand to be corrected by primary control e.g. in Germany is 3000 MW (reference incident),
- For the whole UCTE system, with a peak load of the order of 300 GW and an off-peak load of the order of 150 GW, assuming 1% self-regulation of load, the quasi-steady-state frequency deviation must not exceed 180 mHz and the instantaneous frequency must not fall below 49.2 Hz in response to a shortfall in generation capacity equal to or less than 3000 MW. The overall network power frequency characteristic ($\Delta P/\Delta f$) for the system is set at 18 000 MW/Hz,
- The primary control reserve to be maintained by each control area must be able to be activated within 15 seconds at the latest in the event of a disturbance $\Delta P < 1500$ MW, and on a linear scale between 15 and 30 seconds at a ΔP between 1500 and 3000 MW,
- Each control area contributes to primary control in accordance with its respective contribution coefficient C_i ($C_i = E_i/E_u$, where E_i is the annual electricity generation (in MW) of area i and E_u is the total sum of annual electricity generation in all control areas comprised within the zone of synchronous operation).

If primary control does not offset the imbalance between the generation and load in the prescribed time limits, then the secondary control, activated in the control area where imbalance appeared, takes over from it.

2.3 SECONDARY CONTROL OF FREQUENCY AND EXCHANGES

The secondary control particularly fulfils the task to compensate the power surplus or deficit in that part of the system where it has occurred and for compensation of the instantaneous total system deviation. The function of secondary control in a given control area is as follows:

- Secondary control takes over from the primary control reserve deployed by all members to offset an imbalance between generation and demand; the secondary control reserve will only be activated in the control area where the imbalance appeared;
- The restoration of the synchronous system frequency to its set point value,
- The maintenance of scheduled power exchange programme between the area concerned and all other adjoining interconnected zones;

These actions on generated power and frequency will take place simultaneously, either in response to minor deviations which will inevitably occur in the course of normal operation, or in response to a major discrepancy between generation and demand associated e.g. with the tripping of a generating unit. Parameters for the network controllers of all control areas should be set such that, ideally, only the controller in the zone affected by the disturbance concerned will respond and initiate the deployment of the requisite secondary control capacity.

Characteristics and parameters for secondary control are as follows:

- Secondary control must begin within 30 seconds of the disturbance concerned, i.e. when the action of primary control is complete, even under the most stringent conditions assumed for the reference incident; secondary control must be fully deployed within 15 minutes.
- When the scheduled power exchange between control area and adjoining areas is modified, the set point value of the interchange will be adjusted on a linear basis. The adjustment will begin five minutes ahead of the programme change concerned and will end five minutes later.
- If the loss of the largest generating unit supplying the area concerned is not covered by the secondary reserve of that area, provision must be made for an additional reserve, which will offset the loss of capacity within the requisite time. This reserve may take the form of generating plant with the facility for rapid start-up, the adjustment of set points for generating units in service or load shedding. This additional reserve may also be obtained from other control areas, subject to prior agreement.
- The operator responsible for each control area will undertake the regular assessment of the performance of secondary control, particularly in the case of losses of capacity exceeding 600 MW [3].

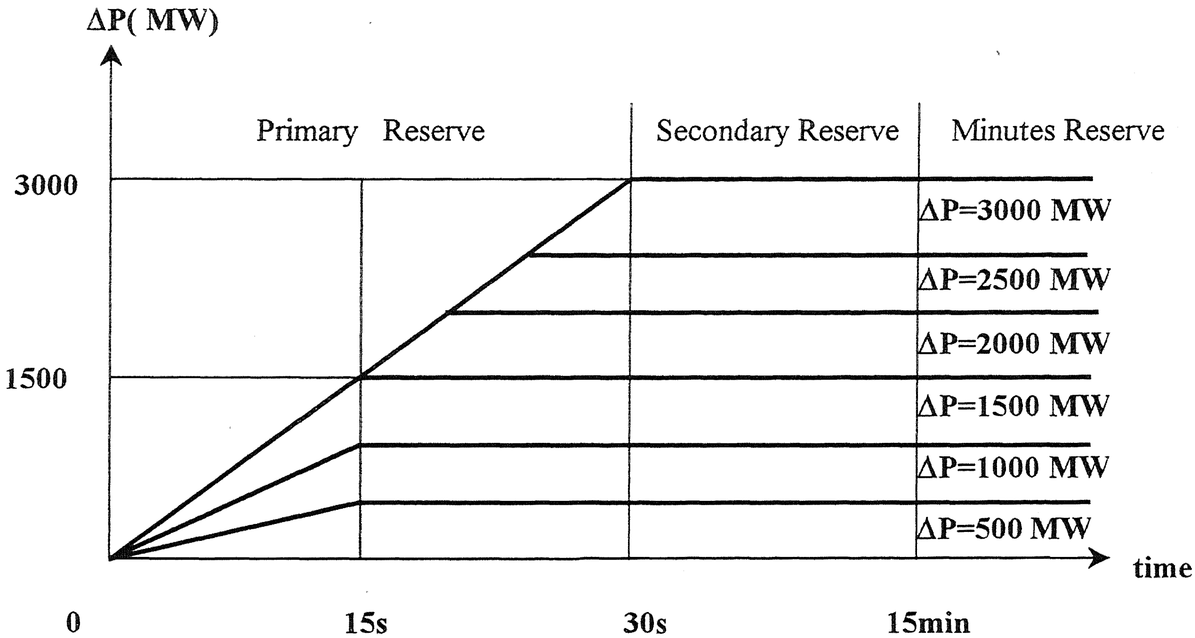


Fig 2.1: Graphical representation of primary, secondary and minutes reserve as a function of time for various imbalances in generation/demand

The Figure 2.1 describes the time limits of when the short-term balancing controls get activated for various imbalances. The droop and characteristics of generating units involved in control must be such that all the reserves will be activated with values that are not lower than those defined by the respective curves.

2.4 VOLTAGE AND REACTIVE POWER CONTROL

The transmission system operator is responsible for the maintenance of the system voltage within a given range at the various node points in his network. The operator must be responsible for reactive power management in the various parts of that network. Since reactive power transmission over long distances is not practical because reactive power transmission will cause voltage drops and losses, so the balance between reactive power generation and demand must be maintained on a regional basis within the area of operation concerned. It is therefore preferable that system operation should be optimised in such a way that the balance of reactive power will be maintained as effectively as possible on a local basis.

In reactive power (and therefore voltage) control, a distinction is drawn between primary, secondary and tertiary voltage control. The voltage regulators of generating units, which will initiate a rapid variation in the excitation of generators when they detect a variation in voltage across their terminals, implement primary control. Other controllable devices, such as Static Var Compensators (SVCs) may also be involved in primary voltage control. Secondary control co-ordinates the action of voltage and reactive power control devices within a given zone of the network in order to maintain the requisite voltage level at a "key node point" in the system. Tertiary control involves a process of optimisation, using calculations based upon real time measurements, in order to adjust the settings of devices which influence the distribution of reactive power (generating unit controllers, tap transformer controllers and compensating devices, such as inductors and capacitors). Where the system load is high, the operator must be certain that, in case of a loss of generation, the remaining facilities will be able to deliver enough reactive power to keep the voltage within the required range. The same applies to the converse situation, where the system load is low and reactive power needs to be absorbed.

Voltage profiles on either side of tie-lines must be harmonised by the operators of adjoining systems in order to allow the effective management of reactive power flows. This applies particularly to cross-border tie lines. Where voltage deviations lead to constraints on adjoining systems on a regular basis, compensating equipment must be installed in order to keep the system voltage within the normal range. The choice of compensating equipment to be used will be established by agreement between the members concerned [3].

Secondary control in a given area will not be affected by third party transmission or loop flow transmission in the area concerned, since (allowing for losses) the value of outgoing power flows will be equal to the value of incoming power flows.

With this knowledge and insight regarding the working of a deregulated market and the technical aspects, the next chapter proceeds to study the electricity markets in Europe along with how regulation is achieved in each of the different scenarios.

Chapter 3

EXPLORATION OF SOME ALREADY EXISTING REGULATING MARKETS IN EUROPE

3.1 ELECTRICITY MARKETS IN THE SCANDINAVIAN COUNTRIES

3.1.1 The Nordel Power System

The Nordel power system comprises of the interconnected power systems of Norway, Sweden, Finland, and part of Denmark. The other part of the Denmark, which is interconnected with the UCTE system, has strong connections to Nordel through several HVDC links. The Nordel system has undergone major changes during the last decade due to restructuring. The Nordic power systems are characterised by a mix of hydro and thermal generation. While Norway has almost 100% hydro generation, Finland has mainly thermal generation and Sweden has an even mix of thermal and hydro generation. The Danish system is unique with a high penetration of wind energy and co-generation from independent producers [5].

3.1.2 The Electricity scenario in the Nordic countries

The electricity sectors of the Nordic countries have co-operated for a number of decades. Due to geographical proximity (augmented by a series of sub-marine interconnectors), the differing balance of fuel-source in the different countries is complementary. The significant hydro capacity of Norway (100%) and Sweden (50%) can, in wet years, provide cheap electricity beneficial to other markets; the significant thermal capacity of Denmark (85%) and Finland (55%) can provide "dry-year" reserve for the hydro countries. At the Nordic level, the main need has been to extend the principles of competition in domestic markets across national borders, to allow and to promote beneficial cross-border electricity trade. The major cross-border restructuring event of the development of a liberalized Nordic market has been the creation of a Nordic power-pool, currently operating across the markets of Norway and Sweden, with Finland joining in 1998 and Denmark in 2000. Since Norway and Sweden had physical as well as financial clearing markets prior to the creation of the Nord Pool (in January 1996), the development of the cross-border market has been a process of refinement and convergence of existing national arrangements.

In Norway, competition was introduced in 1991 and the national grid was unbundled in 1992. In Sweden, the national power market was deregulated in 1992 with open access introduced in 1995 and full market deregulation introduced in 1996. In Finland, the two national grids were unbundled in 1995 and merged into one company in 1997. Open access was introduced in 1995 for supplies greater than 1MW and full market de-regulation by 1997. The Nord Pool is now also involved in the trade of hourly spot and futures contracts.

The restructuring needs at the local level varied in each country. In Norway, electricity costs were seen as high (relative to what should be achievable with such considerable hydro resource) and investment decisions were not always optimal. In Sweden, the introduction of competition and free-market principles in the electricity industry (and many others) was seen as part of a program aimed at lifting the country from the economic stagnation into which it had fallen in the late nineteen-eighties. In Finland, the changes in Norway and Sweden have given impetus to reform. In Denmark, less pressure has existed to reform the present structure of the electricity industry, other than to accommodate European Union and Nordic developments.

Differences in restructuring which have taken place at the local level to effect liberalisation reflect varying national priorities. In particular, approaches to ownership and legal structure have differed. In Denmark and Norway, no significant changes to existing ownership or legal unbundling were seen as a condition of liberalisation, whereas, in Finland and Sweden, radical ownership changes and legal unbundling have taken place.

In Norway, Statnett is the transmission system operator. In Sweden, Svenska Kraftnät, which is owned by the Swedish government, is the transmission system operator. In Finland, Fingrid, which is partly government owned, plays this role. In Western Denmark the transmission system operator is Eltra, which is owned by the local grid companies in Western Denmark, while Elkraft System, which is also owned by the local grid companies, is the transmission system operator in Eastern Denmark [3]. The development of the liberalised markets brought an important feature of the convergence of conditions in different markets to allow cross-border competition. An overview of the restructuring process in the Nordic countries is presented in the next subsection.

3.1.2.1 Restructuring of the Nordic power systems

Electricity liberalisation and restructuring in the Nordic countries (Denmark, Sweden, Norway and Finland) has occurred on two levels. At the national level, each country has pursued its own liberalisation and restructuring process, encountering nation-specific issues on the way. At the Nordic level, parallel liberalisation and restructuring has taken (and continues to take) place so as to allow the creation and development of a Nordic power market.

The restructuring started in 1991 with deregulation of the Norwegian electricity market. Sweden followed in 1996, and Finland joined the common Nordic market in 1998. Restructuring, was done mainly with the following issues:

- Unbundling of services.
- Deregulation within trade of electrical energy.
- Dis-aggregation of utilities. Economically and functionally separate units are established within power generation, transmission and distribution, power markets and retail sales.

In the Nordic system, the major arguments for restructuring of the electricity market were to:

- Avoid excessive investment.
- Improve selection of investment projects.
- Create incentives for cost reduction.
- Create equity among consumers.
- Achieve reasonable geographical variations.

The main actors in the Nordic power market are:

➢ **Regulator**

The Regulator grants regional concessions and concessions for trade in electrical energy and has an important role in supervision of the monopoly operations in transmission and distribution. For example, the Regulator of the Norwegian power industry is the governmental body "The Norwegian Water Resources and Energy Directorate" (NVE).

➢ **Market Operator**

The Market Operator is responsible for the market clearing process in what is called the organised markets. The operator of the common Norwegian/Swedish/Finnish market is Nord Pool. Nord Pool is also open to market participants without physical access to the Nordel grid.

- **System Operator**

In Norway, the main grid company, Statnett SF, has the system operator responsibility. Similarly, there are independent system operators in Sweden and Finland, Svenska Kraftnät and Fingrid, respectively. These companies are also the main transmission grid owners in their respective countries.

- **Market Participants**

The Market Participants are buyers and sellers in the market, and include generators, distributors, industry, and traders/brokers.

- **Network Owners**

The Network Owners have by regulation been given the responsibility for generating and distributing metering and settlement data, and keeping continuous track of the information so that equal opportunities are given to all the competitors.

- **Retail Sales**

Retail sales are yet another service made possible through deregulation, but is only indirectly related to the power exchange. Retail sales mean that the individual electricity consumers are free to choose from which power company they buy their energy; totally independent of which network owner (distribution grid) they are connected to [5]. The above sections have given a general idea of the electricity markets and the restructuring process of the Nordic power system. Now we look into each of the markets (Norway, Sweden and Finland) separately along with greater emphasis on their regulating concepts and their functioning.

3.1.3 The Electricity market in Norway

Norway deregulated its electricity markets in 1991 and 1992. The 1990 Norwegian Energy Act, which became effective in January 1991, called for increased competition in the production and sale of electricity. It also allowed the consumers to select their suppliers. Statkraft, the state power company, was divided into two independent government-owned companies; a production company (Statkraft SF) and a transmission company (Statnett SF) [8].

Statnett SF was established as a transmission system operator from 1992 and in 1993 it established the power exchange called Statnett Marked only for the Norwegian market. The power exchange was then extended to a common Norwegian-Swedish power exchange from 1996 with its name changed to Nord Pool and owned by the two national grid companies, Statnett SF in Norway (50%) and Svenska Kraftnät in Sweden (50%). In Norway, Statnett is responsible for co-ordinating supply and demand in the power system. Being a transmission

system operator, Statnett owns and operates large sections of the main Norwegian power grid and the Norwegian section of power lines and subsea cables to other countries.

The role of Statnett and its responsibilities are:

1. Its area of responsibility was and is to develop the Norwegian transmission grid and international connections, as well as the development, maintenance and technical operation of sections of the main grid, main grid tariffs and the aforementioned system operator responsibility, including key operating functions.
2. It is the Norwegian national co-ordinator monitoring that power is generated in equal amounts as is used and providing buyers and sellers with the necessary transport route. Statnett makes the grid available for an open power market and ensures that physical limitations are kept to. This transmission system is the physical marketplace for electric power.
3. Statnett is responsible for the system safety of the Norwegian power system in the short and long term and to help ensure that the transmission grid is developed in a manner that is efficient and beneficial to society. Its goal as a transmission system operator in Norway is to be a neutral facilitator for the power market, based on socio-economic criteria, and to ensure at the same time that the customers' demand for cost-effective operations is fulfilled.
4. It owns approximately 80% of the Main Grid, and conducts the electricity in this transmission system in such a way that the system is utilised to its fullest. Statnett's clients are power producers, large energy companies and a few large industrial clients who are directly connected to the nation-wide Main Grid.
5. Statnett is also responsible for keeping the Norwegian power system in balance, and thus it is responsible for the overall physical management and control of the national power system. Technically this means that the frequency is maintained at 50 Hz.

3.1.3.1 The Norwegian power market

The Norwegian power market had been formally open to competition since 1991, but real market access for all the end user groups was not established until 1995 through settlement based on the adjusted system load profile. In order to organise a power market it is important to distinguish between network operations and power trading. Participants who are called *entities with balance responsibility* in the regulations carry out power trading. An entity with balance responsibility is responsible for the difference between its contractual purchase and

sale obligations and the metered consumption or input in the network areas one is operating in. The entity with balance responsibility is therefore charged for regulating power based on the physically metered power.

An entity with balance responsibility that sells power to end-users is called a *supplier* (electricity producer) in the Norwegian rules and regulations. An entity with balance responsibility that only buys and sells on the wholesale market is therefore not a supplier pursuant to the rules and regulations. Both end users and network owners can themselves be entities with balance responsibility if they are charged directly for regulating power. These end users will normally be large industrial concerns with a high consumption of energy that buy power on the wholesale market themselves. Network owners with balance responsibility will be the entities that buy network losses on the wholesale market. Table 3.1 gives out the different market participants in Norway and the role they play in the functioning of the power market [4].

Power pool	Trading concession holder (Statnett) who is responsible for the settlement of regulating power pursuant to his trading concession.
Entity with balance responsibility	Trading concession holder for whom regulating power is settled in the network owner's power network. End users and network owners who are responsible in the regulating power market are regarded as entities with balance responsibility.
Supplier	Entity with balance responsibility that sells electrical energy to end-users.
Network owner	Entity with balance responsibility that sells electrical energy to end-users.
End user	Buyer of electrical energy who does not resell.
Spot electricity market	Market where contracts for the purchase and sale of electrical energy are traded on an hourly basis for the next day. Only Nord Pool ASA has a concession for such a market in Norway.
Regulating power market	Market for handling imbalances in the Norwegian power system after the spot electricity market has been cleared. Statnett has a concession for organising the regulating power market.

Table 3.1: The Norwegian power market participants

The transmission system operator is at the same time responsible for ensuring that the transport grid used is constructed in accordance with the market's needs and that socio-economic criteria are used for the solutions that are selected. The transmission system operators may weigh different solutions such as agreements to disconnect consumption and the construction of new power lines up against each other and choose the most profitable on the basis of an overall socio-economic assessment. The figure 3.1 gives the complete details of how the power market functions regarding the trading of power and its settlement between the market participants [7].

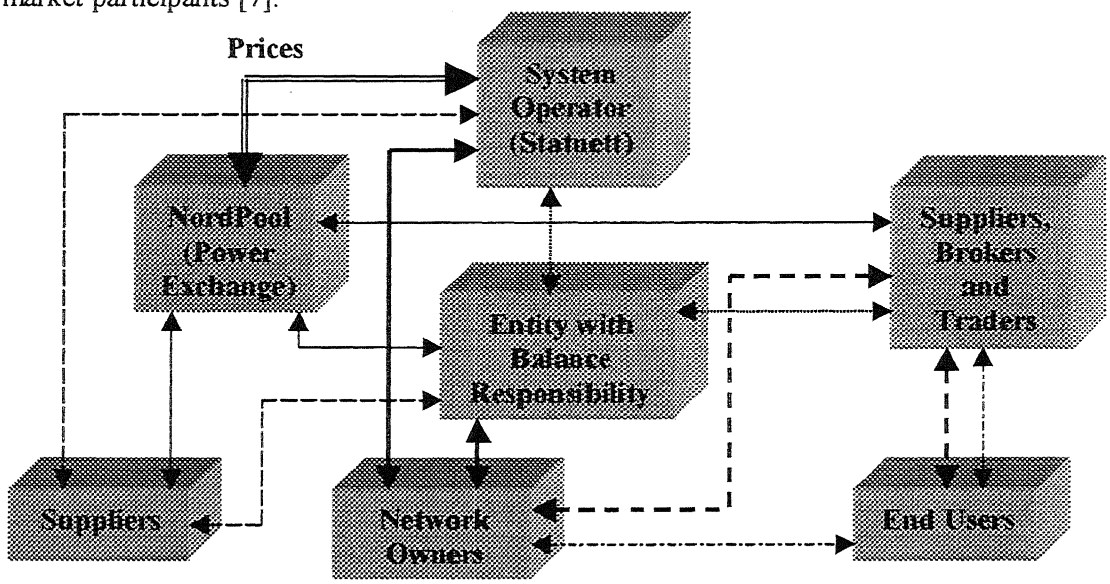


Fig 3.1: The total power market in Norway

◄──►	Metering	◄──►	Power trade
◄- - -►	Metering, Change of supplier	◄·····►	Metering, Settlement, Production Forecast
◄-·-·-►	Metering, Invoicing	◄– – –►	Metering, Power trade

The *Network owner* is one who meters all electricity consumption or power input associated with his power network. The network owner prepares and submits the settlement data to Statnett while the entity with balance responsibility themselves report their power commitments, but they do not provide settlement data. The power commitments of an entity with balance responsibility may be established through buying or selling on the spot electricity market or through bilateral contracts with another entity with balance responsibility.

In Norway, the exchange of power both in physical and financial form takes place at Nord Pool (The Nordic Power Exchange). Nord Pool has two marketplaces: Elspot and Eltermin. Elspot is a market where physical kilowatt-hours are traded in the same manner as shares are traded for example in a stock exchange. Elspot is the spot market for power. Eltermin is a marketplace for financial futures trading, where price-hedging contracts are traded [4].

Statnett is responsible for the main Norwegian power grid – and it has a duty to ensure that the grid is open to all the participants in the power market. If the consumption exceeds the production, the frequency will drop to less than 50 Hz and then Statnett must call a regulating generator and ask him to "input more power into the grid" or ask a consumer to use less. If the production is too great and it exceeds the consumption, then the frequency will increase to over 50 Hz. Statnett must call a producer then and ask him to "input less power into the grid".

The volume of power that Statnett trades in this manner is called *regulating power.* Statnett chooses who will change their production or consumption based on a price offer that the producers and consumers have given for this. The producer or consumer who has given the lowest price for the change that is required will be chosen.

3.1.3.1.1 The Physical power market

Nord Pool consists of two markets for physical trade; a daily spot market (day exchange) and a market for physical balance (Regulating exchange). The spot market clears demand and supply and sets a spot price 12-36 hours prior to the actual delivery. Any difference in demand or supply from the market balance on the spot market is later offset on the regulating power market just before the actual delivery takes place. Suppliers of regulating services must be able to regulate their supply within short notice in order to meet the requirement of the instant physical balance between supply and demand [9].

Market participants who desire to purchase power via Nord Pool's Elspot marketplace must submit their bids to Nord Pool no later than 12 noon the day before they desire delivery. Correspondingly, the market participants who desire to sell power via Elspot must send their bids to Nord Pool the day before they desire to make delivery. This trading is done for the next day's 24 hours and takes place once a day, every day of the week.

The bids to buy and sell for each hour the following day are compiled by Nord Pool into an overall curve for the demand and an overall curve for the supply (Fig 3.2). The system price is read from where the two curves intersect with the assumption that there are no bottlenecks. Nord Pool sets a system price for each hour during the following day. The price can vary from hour to hour, but it is fixed for one hour at a time.

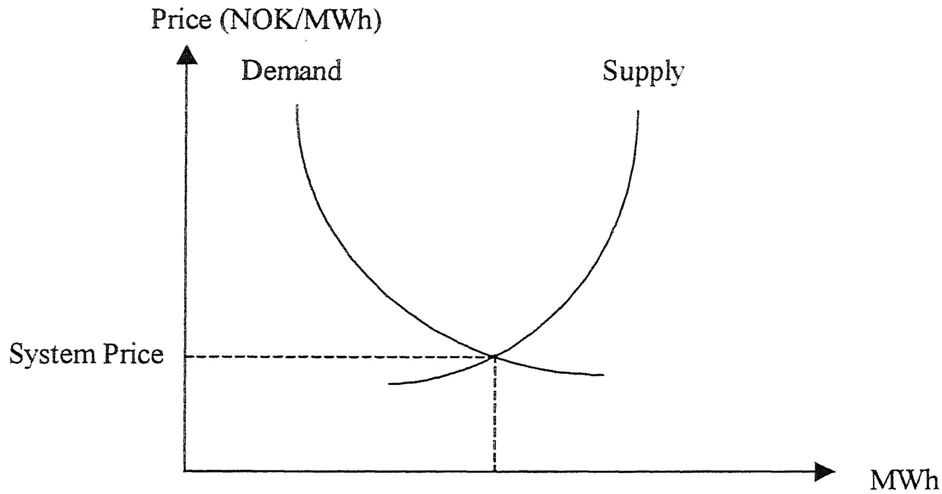


Fig 3.2: Calculation of system price

When Nord Pool has made its calculations, it releases the prices for the following day and tells the market participants how much power they have purchased or sold for the various hours of the following day, and the transmission system operators are notified of the contracted purchase and sales volumes. This can be entered then in the balance accounting for various market participants [4].

3.1.3.1.2 The Regulating Exchange

The *Regulating Exchange* is an hour-to-hour exchange and handles the necessary adjustments when the situation does not follow the supply and demand plan. Big price variations may occur from one hour to the other, for example, at a sudden drop of power production or if a plant suddenly falls off or at sudden power transfer limitations. Sometimes producers try to regulate their production units against the situation at the regulate-exchange market. A requirement for taking part in this trade is the ability to deliver power rapidly; 15 minutes are the maximum time. Thus, ordinary consumers have no access to and are seldom affected by this trade.

The producers with fluctuating power production in the Norwegian power market need to buy regulation services in order to fulfil their spot market contracts. These producers must pay a limited premium of readiness in addition to the spot price (shown in Fig 3.3). The level of the premium of readiness for down regulating power is strongly influenced by the level of the spot price, while that for up regulating power is less correlated to the spot price. Also, the slopes of the price curves for regulating power differ for up and down regulation.

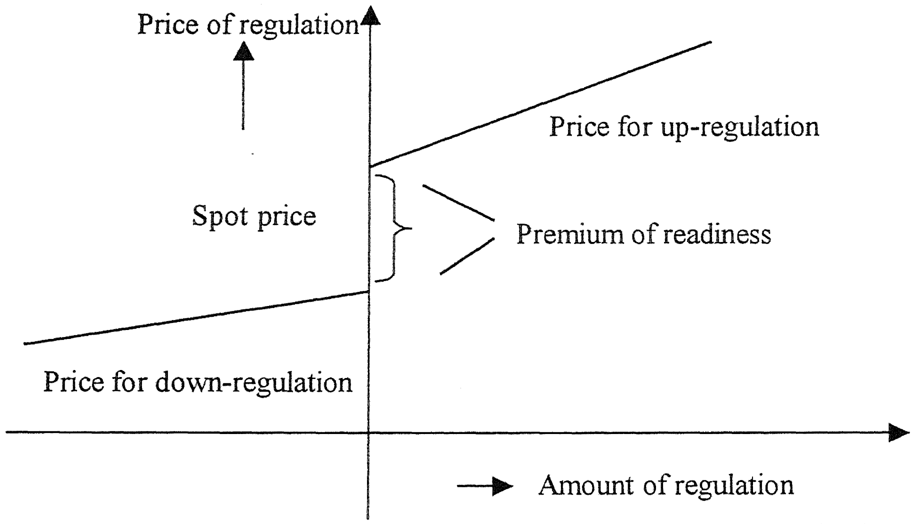


Fig 3.3: Prices at the regulation power market for physical balance

For the regulating market, the bids from producers and consumers are obtained in which market players quote a price and quantity for upward and downward adjustment. The TSO sorts the bids for upward adjustments with the lowest price first and the bids for downward adjustments with the highest price first. The *resultant price/quantity* list is used for achieving the balance between consumption and production from one minute to the next [9].

The Figure 3.4 illustrates the flow of information and division of responsibility for regulating power settlement. The physical power market (ELSPOT) supplies the information of the spot market to the Power Pool (Statnett), which along with the information provided from the bilateral contracts is used to establish the power commitments or contracts (Fig 3.4). In the Norwegian rules and regulations it is the network owner's obligation to send the settlement data to the power pool on behalf of the individual entities with balance responsibilities who sell power in their concession area.

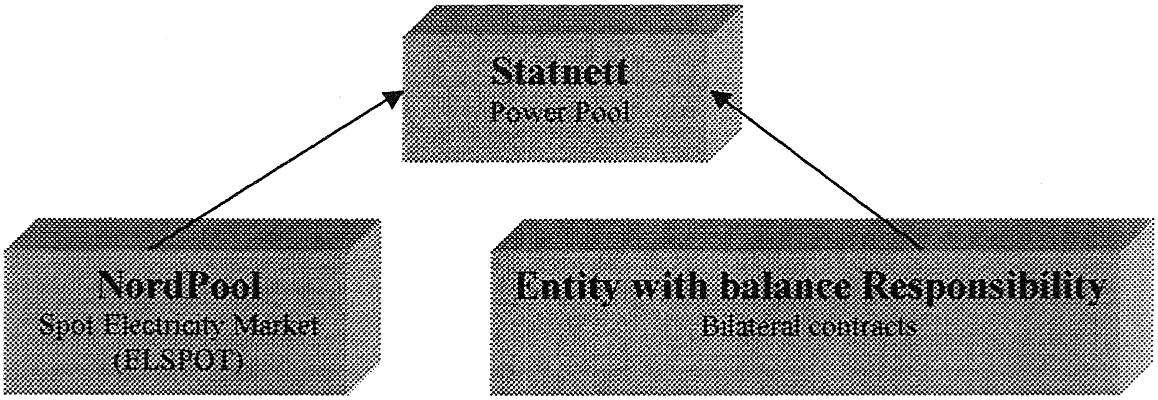


Fig 3.4: Information flow for trading on the spot electricity market and bilateral trading

The network owner is responsible for all the metering data, and it ensures that the power pool receives settlement data that coincides with the total input to the network owner's power network. This is shown in the Figure 3.5. The parties that are involved in regulating power settlement are the network owners, entities with balance responsibility and Statnett as the power pool. Pursuant to the regulations the network owner sends settlement data to Statnett three days after the delivery week. This means that the network owner sends Statnett the 7 times 24 hourly values for the previous week on Wednesday for each individual entity with balance responsibility that settles power in his network. The network owner does not distinguish between the hourly metered and calculated values in relation to Statnett, he sends the accumulated settlement data for each entity with balance responsibility. The network owner sends the same data to the entities with balance responsibility.

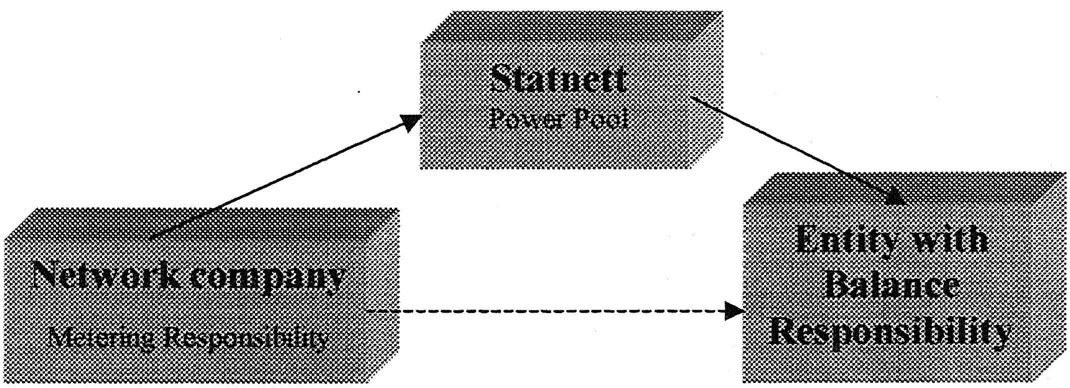


Fig 3.5: Regulating power settlement based on reported purchase and sales commitments and settlement data from the network owner

The entities with balance responsibility use this data as a basis for controlling the settlement from Statnett. The network owner also sends hourly values for the installations that the individual entities with balance responsibility deliver power to. In addition, the network owner sends the adjusted system load profile share for the entities with balance responsibility. This is data that the entities with balance responsibility use as a basis for invoicing their customers. Statnett has nine days after the delivery week to carry out a settlement in relation to the entities with balance responsibility by means of a credit or debit [6].

3.1.4 The Electricity market in Sweden

In Sweden, the production and sale of electricity was separated from the network operation on a national level in 1992 with open access introduced in 1995 and full market deregulation introduced in 1996. The Swedish electricity market consists of many independent players. These are:

- electricity producers
- network owners
- the system operator (Svenska Kraftnät)
- electricity consumers
- electricity traders in the role of electricity suppliers and/or balance providers
- market places, primarily the power exchange Nord Pool [11].

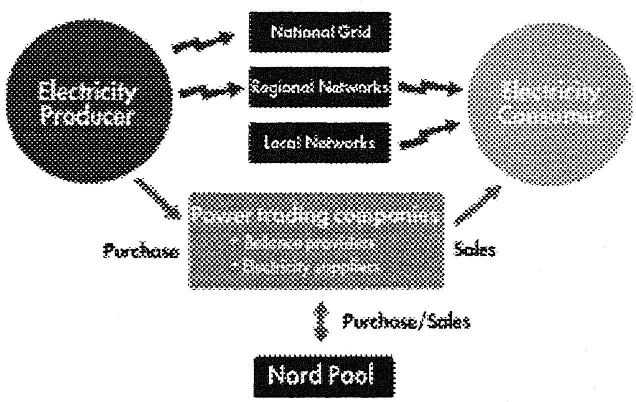


Fig 3.6: The physical flow of electricity and the relationships between the players in the Swedish electricity market

Svenska Kraftnät is the System Operator of Swedish electricity market and the utility charged with managing and operating Sweden's national grid and overseas links. It has the overall responsibility of electricity plants working together in an operationally-reliable way along

with ensuring the reliability of service so that a balance is maintained in the short term between the production and the consumption of electricity both within the country as a whole and within parts of it (system responsibility).

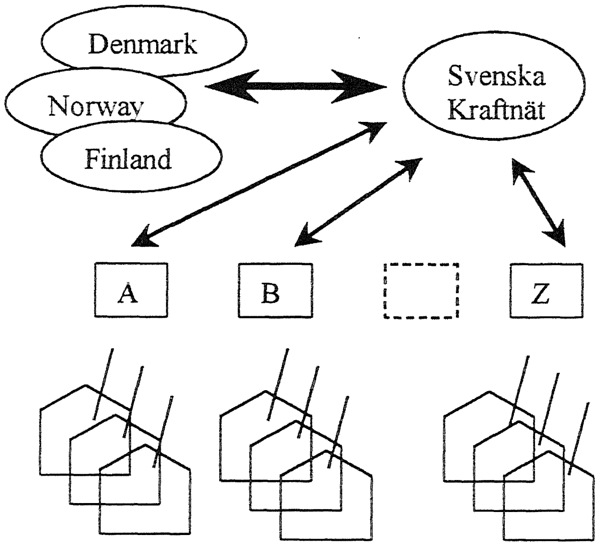
The task of maintaining the balance between the production and consumption of electricity is performed by the Operating Balance Service, which monitors the electricity balance in the short term and maintains the frequency of the system, which is a measure of the balance: normally within a specific range around 50 Hz (±0.1 Hz). Whenever the frequency deviates from normal values the balance service orders the regulation resources. These resources have been put at the disposal of balance providers by way of bids to Svenska Kraftnät.

Players signing the Balance Obligation Agreement of the Swedish power market are called *balance providers* (50 or so players, including the biggest producers) with whom Svenska Kraftnät collaborates. Through agreements, these players have assumed the balance responsibility for one or more electricity consumers. Balance responsibility entails assuming the financial responsibility for Sweden's electricity system, hour by hour, being supplied with the same amount of power that is being used by the electricity consumers for whom the balance responsibility has been assumed.

There are three levels of responsibility for balance on the Swedish electricity market (Fig 3.7).

1. On the national level, Svenska Kraftnät is responsible for the balance of the entire electricity system, under the Electricity Act. This means that the balance service maintains the electricity balance between production and consumption on an instantaneous - or minute-by-minute - basis. The balance service also collaborates with similar functions in Norway, Finland and Denmark. By monitoring and, then required, correcting imbalances between the Nordic countries, the system operators can ensure that each country is doing its fair share of the necessary joint regulation work.
2. The second level of responsibility consists of the balance providers, which are obligated under the Balance Obligation Agreement to maintain their company balances on an hourly basis.
3. On the third level of responsibility, there are the electricity suppliers who supply electricity to consumers, or those who are consumers themselves. These players have not signed a Balance Obligation Agreement with Svenska Kraftnät (SvK), instead

having to enter into an agreement with balance providers who will then manage the balance on their behalf.



Balance Service

- Maintains the country's balance
- Trades in regulating power (frequency regulation)

Balance Providers

- Hourly company balance
- Offer regulating power

Electricity suppliers

- Supply electricity to the consumers

Fig 3.7: The three levels of responsibility for the electricity balance

A balance provider's balance appears as in Table 3.2 below. The supply of electricity can consist of the company's physical input (production) and any purchases from other players under fixed agreements, from the spot market or from Svenska Kraftnät (e.g. regulating power).

Input of Electricity	**Output of Electricity**
• Measured production • Reported purchase (firm power supply including regulating power)	• Measured consumption (including profiles) • Reported sale (firm power supply including regulating power)
Total input	Total output

Balance power = total output –total input

(positive value = SvK sells; negative value =SvK buys)

Table 3.2: Company balance (per hour) with reference to input and output of electricity

All this is compared with the physical output (consumption) of electricity and any sales to other players under fixed agreements, to the spot market, or to Svenska Kraftnät (e.g.

regulating power). The difference between the supply and the output is settled as the purchase or sale of *balance power* [11].

3.1.4.1 The physical balancing of power

The physical balances (means that the production and purchasing are in balance with consumption and sale) in electricity of the balance providers and other players can be traded right up until just before the delivery hour. From the Fig 3.8 we can see that the trading takes place on the spot market of the power exchange Nord Pool, which closes at 12.00 the day before delivery. Then trading on the adjustment market of the EL-EX power exchange takes place from 15.00 on the day before up until two hours prior to delivery, or bilaterally.

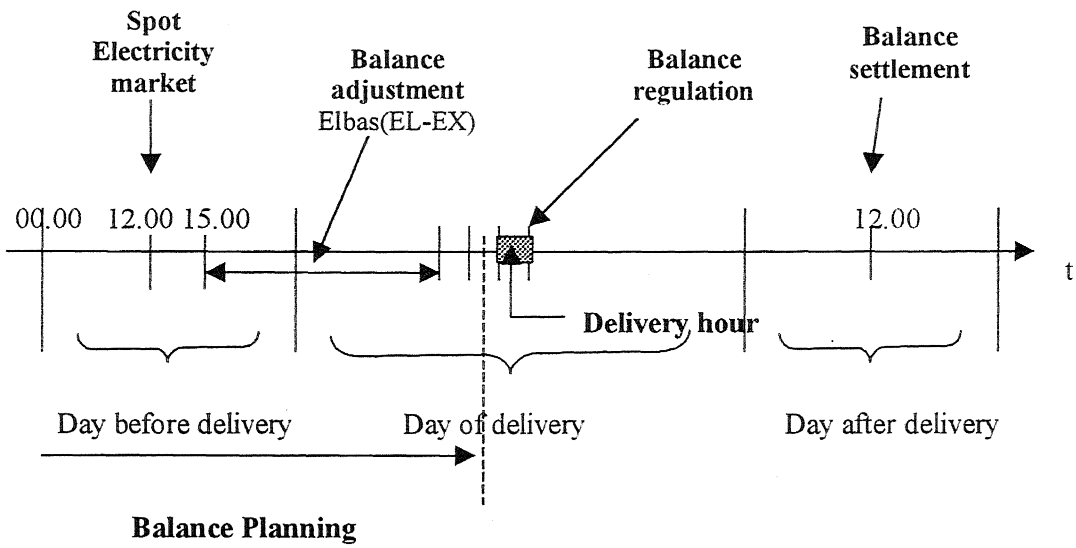


Fig 3.8: Balance and trading time table

The Elbas market supplements Elspot and the national Nordic regulating power markets or balance services by providing continuous power trading covering individual hours, up to two

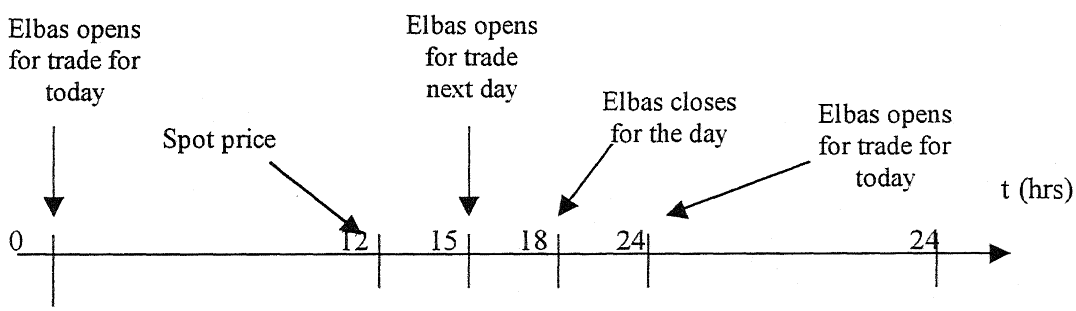


Fig 3.9: Trading in the ELBAS market

hours prior to delivery. The Elbas market is based on existing EL-EX hour contracts between Finland and Sweden. For each day of the present trading week, individual, one-hour contracts for power are quoted. Contracts are traded for at least 7 hours and at most 31 hours for the following day. Trade is conducted until 2 hours before the hour of delivery. The priority of recording orders is: first, according to price, and second, according to the time placed. The Elbas trading day lasts 18 hours, between 00:00-18:00 CET (Central European Time), every day of the year while contributing for balance of power in the market [10].

The balance planning is done just before the delivery hour after analysing consumption forecasts, production plans and commercial trading. The regulation of power through balance regulation is automatic and subordered. Later, balance settlement is carried out on an hourly basis the day after the day of delivery. Settlement is based on firm power agreements reported by balance providers and measurements reported by network owners [11].

3.1.4.2 Balance regulation

The balance service takes over the balance management when the delivery hour begins. Prior to maintaining the physical balance - balance regulation –Svenska Kraftnät regularly accepts bids – volume (power in MW) and price (SEK/MWh) – from producers who are willing to quickly (within 10 minutes at the outside) increase or decrease their level of production.

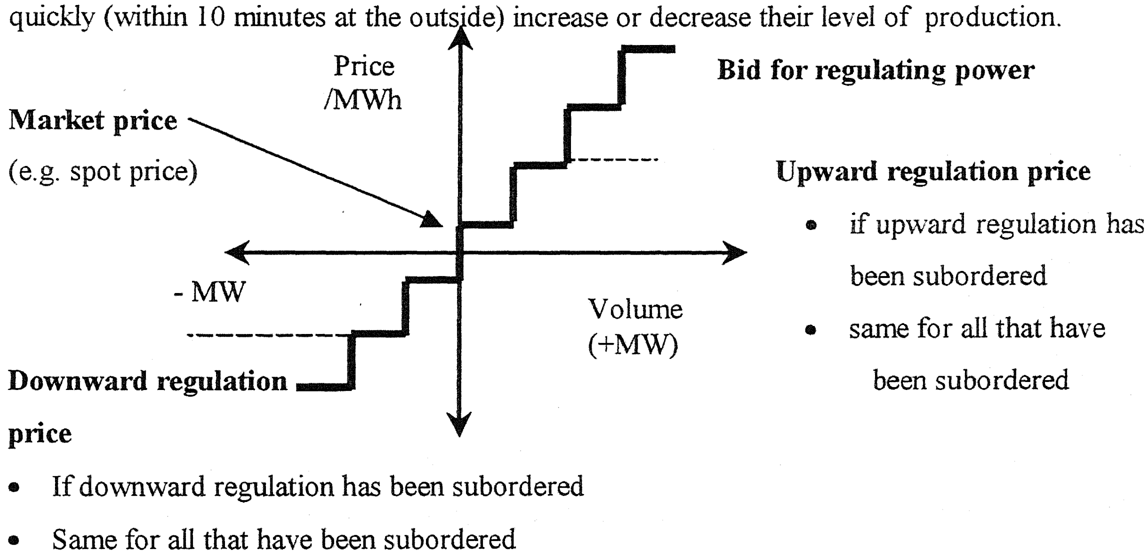


Fig 3.10: Bids for balance regulation

Consumers, too, can submit bids for increasing or decreasing their level of consumption. Bids for balance regulation are arranged in order of price and form a "staircase" for each hour of operation (Fig 3.10). When central measures are subsequently required to adjust the electricity balance, the balance service activates the most profitable bid [11].

This regulation using manual interventions is combined with the automatic frequency-controlled regulation of the generators at certain power stations (that are equipped with special regulators for this purpose). Svenska Kraftnät purchases such regulating power, via weekly and 24-hour contracts, from electricity producers that have these possibilities. These bids are submitted per sectional area at the latest 30 minutes prior to the beginning of the hour of delivery and must be available throughout the entire hour of delivery in question, as well as 10 minutes prior to this. The production units or consumption objects for activation in balance regulation called as *regulation objects* must be at least able to regulate a capacity of 25 MW upwards or downwards within 10 minutes. At the end of each hour, the regulation price is determined in accordance with the most expensive measure taken during upward regulation (the balance service purchases electricity), or the cheapest measure taken during downward regulation (the balance service sells electricity), used during the hour - as in Fig 3.9. This final regulation price applies to all those selected to regulate the balance upwards or downwards.

3.1.5 The Electricity market in Finland

In Finland, liberalisation of the electricity sector began in 1995. This was done through the adoption of the Electricity Market Act, which entered into force in June 1995 that says that all consumers can buy electricity at the market (from pool, bilateral contracts with domestic or foreign producers, distributors, electricity brokers etc.). In parallel with this institutional restructuring the power utilities have been reorganised completely. The integrated utilities have been split up into entirely separate business units: network operations, maintenance, generation and power sales and trading business.

In Finland, electricity is generated by about 400 power plants. There are about 120 electricity producers and vendors in the country. The combined production of electricity and heat accounts for about 32%, nuclear power for 27%, hydro power for 16%, and conventional condensing power for 15% of production. Thermal and hydropower plants mostly generate power in Finland. Windmill installations also produce a small volume of electricity. The number of power plants is large, but the three largest producer groups are responsible for three fourths of electricity production. The three largest producers are Fortum Power and Heat Oy (with a share of about 40%), Pohjolan Voima Oy (with a share of about 23%), and the separate power producers of distribution companies (with a share of about 21%). There is a fourth group of power plants owned by industry, and they represent about 16% of power

production. The voting rights are however divided differently: Fortum Heat and Power (1/3), PVO (1/3), the state (1/6), and institutional investors (1/6) [13].

The power transmission network comprises the national grid, separate regional networks, and distribution networks controlled mainly by local supply companies. The companies selling network services are called grid operators, regional network operators, and distribution network operators, according to the network they operate. Network operators are also responsible for the condition of the electric network and for the quality of the electricity supplied to customers.

Each network company holds a regulated monopoly over an area, subject to the requirements of the Electricity Market Act. A number of wholesalers and producers have bought several of the network companies, integrating vertically by acquiring distribution channels. As a whole the players in the Finnish electricity market are:

1. the national grid (Fingrid) and its licensed operators,
2. regional network operators,
3. local distribution network operators,
4. electricity generators and retailers,
5. electricity users and
6. the electricity exchange (EL-EX spot market) [12].

The transmission system is owned and operated by Fingrid plc., which is jointly owned by Fortum Heat and Power (25%), PVO (25%), institutional investors (38%) and the state of Finland (12%). Fingrid plc., is a national grid company, which is responsible for the technical operation of the Finnish power system. The company sells grid services to all parties in the electricity market on equal and non-discriminating terms. Fingrid plc. attends to these tasks through its three subsidiaries : Fingrid Oyj, Fingrid System Oyj and Fingrid Varavoima Oy (for controlling and maintaining the gas turbine capacity).

Fingrid Oyj is the national grid operator in Finland. It is responsible for ensuring the technical reliability of the electricity transmission system in Finland and it sells main grid services to all electricity market parties by applying equal terms.

- It was established on 29 November 1996 and started operations on 1 September 1997.

- Fingrid Oyj owns 99.5 per cent of the Finnish main grid and all the major interconnections.

Fingrid System Oy maintains the technical functionality and operational reliability of the Finnish power system as well as national power balance management and balance settlement and is responsible for the planning and supervision of the operation of the main electricity transmission grid [16].

The Energy Market Authority (EMA) regulates the electricity market in Finland. The EMA supervises electric network operations and the pricing of network services. The Authority monitors the implementation of the Electricity Market Act. The Electricity Market Act contains the following public service obligations:

- a net operator must maintain, operate and develop the network and the connection to other networks in accordance with the reasonable needs of the customers;
- a net operator is obliged to connect consumption sites and generating installations against reasonable compensation;
- a net operator is obliged to transmit the electricity against reasonable compensation;
- a net operator is obliged to apply a tariff system which do not depend on where in its area the customer is located geographically (postage stamp principle);
- a net operator must ensure that equal types of customers pay the same tariffs for the transport of the electricity;
- the distribution operator has the sole right to construct a distribution network within its area;
- an electricity retailer in a dominant position has an obligation to deliver electricity at reasonable prices to customers without any other economically opportunities to buy electricity via the market [13].

The EMA supervises the companies to introduce measures to promote publicity regarding statistics, analyses etc. and reactive measures if somebody infringes the law. EMA also controls monopoly activities like- network pricing, pricing of electricity to captive customers and terms of sales of network services. It issues licences for network operations and collects and publishes price information. EMA along with the Net Operator and Electricity vendors set the tariffs and terms within the framework of laws to bring out competence in the market. These terms are regarding the sale of electricity, the services of the network that are provided by the net operator to electricity vendors as well as to customers and are accordingly classified

as sales contracts, network contracts and network service contracts respectively. These contracts involved in the purchase of electricity are shown in the Fig 3.11 below.

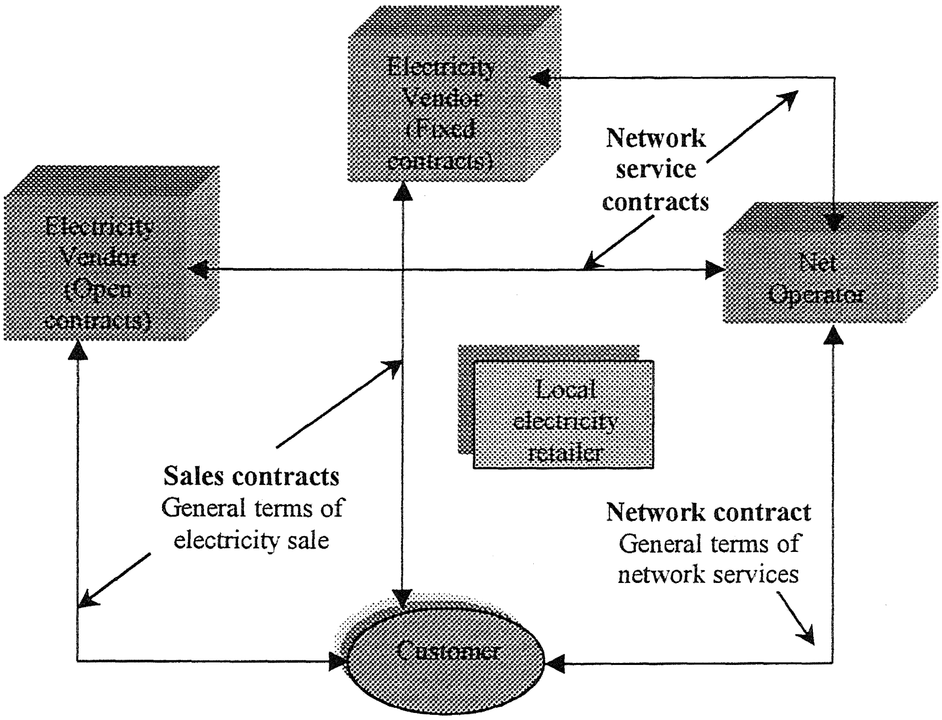


Fig 3.11: Electricity purchase contracts

Since no licence is required for selling electricity, anyone can act as an electricity vendor in Finland. There are more than a hundred electricity vendors in Finland, the majority of which are also active in distribution network business. Recently, a number of independent electricity suppliers and dealers, who are not involved in network activities, have entered the market. The largest electricity wholesalers are Fortum Power and Heat Oy, Teollisuuden Sähkönmyynti Oy and Vattenfall from Sweden. They sell electricity directly to large-scale customers and electricity retailers. Fortum Power and Heat Oy and Vattenfall own distribution companies as well.

The electricity retailer who is in a dominant market position in the geographical area of responsibility of a distribution network operator has an obligation to supply electricity in the area concerned. It is the electricity retailer's obligation to supply electricity on the request of the customer and at a reasonable price, if no other competitive sources of supply are available

to the customer. Electricity Exchange EL-EX Nord Pool operates in the Finnish electricity market, supplementing the procurement and selling possibilities of electricity suppliers and large-scale electricity users. The national grid company owns 50% of EL-EX Nord Pool Fingrid Plc. and 50% by the Swedish Svenska Kraftnät [14].

3.1.5.1 The regulation power market

3.1.5.1.1 General

National balance management means the maintenance of balance between power generation and consumption in the entire Finland. *Balance provider* provides the prerequisites for the management of national power balance and transmissions in the national grid to Fingrid System Oy, thus promoting the correct pricing of balance power and enabling balance settlement of the final hourly balance of Balance Provider. Balance provider also supplies preliminary planning information for use as the basis of system operation and planning of balance management no later than at 19.00 on the day preceding the day of use. This includes a production plant specific or generator specific production plan on the power plants of Balance Provider, a consumption plan on loads participating in the maintenance of reserves and a real-time balance error calculation if Balance provider conducts balance management for a specific hour of use [15].

The maintenance of power balance in the Finnish power system is based on a setpoint value obtained on the basis of power trading between Finland and the other Nordic countries, defined by Fingrid System Oy. On the basis of the frequency error, the generation or consumption is regulated on the inter-Nordic regulation power market either up or down. After each expired hour, the price for up-regulation and down-regulation is defined. The price applies to all regulation implemented in national balance management in the balance settlement of the hour in question. The price of regulation power is determined according to the prices of ordered regulations [16].

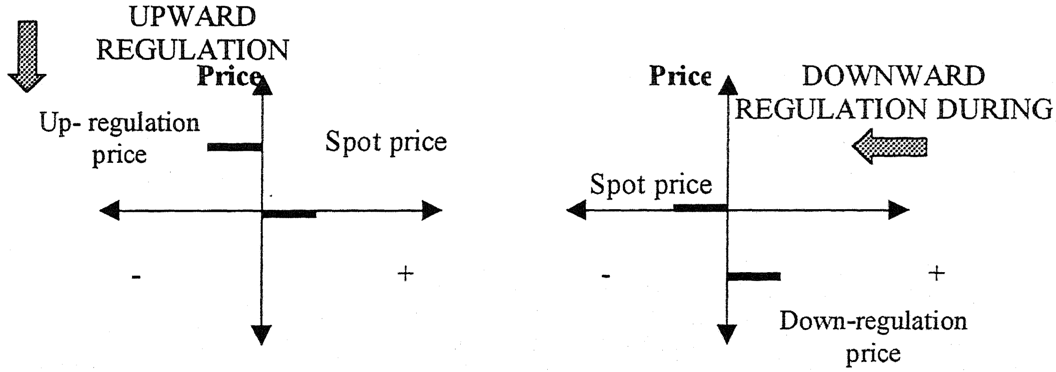


Fig 3.12: Settlement curves for up and down regulation

An offer for an increase in generation or a reduction in consumption is called an *up-regulation bid*. In up-regulation, the Balance provider (a party of the electricity market who balances the difference between its power generation/procurement and consumption/deliveries through balance power trading with Fingrid System Oy) sells power to Fingrid System Oy. An offer for a reduction in generation or an increase in consumption is called a *down-regulation bid*. In down-regulation, balance provider purchases power from Fingrid System Oy.

The highest price of up-regulation used during the hour will be the price of balance power obtained by balance provider from Fingrid System Oy (sale price of balance power). If no up-regulation has been made or if the hour has been defined as a down-regulation hour, the price for price area Finland in Nord Pool (Elspot FIN) is used as the sale price of balance power. On the other hand, the lowest price of down-regulation used during the hour will be the price of balance power fed to Fingrid System Oy by balance provider (purchase price of balance power). If no down-regulation has been made or if the hour has been defined as an up-regulation hour, the price for price area Finland in Nord Pool (Elspot FIN) is used as the purchase price of balance power.

The settlement curves in Fig 3.12 tell how the balance providers pay or get paid for their balance power. If *upward regulation* alone has been ordered, the up-regulation price applies to players with a negative imbalance, while the others settle at spot market prices. If *downward regulation* alone has been ordered, the down-regulation price applies price to players with a positive imbalance, while the others settle at the spot market price.

3.1.5.1.2 Rules for bidding

All the suppliers of power, which can be regulated, make bids on their free regulation capacity to the regulation power market maintained by Fingrid System Oy. The bids are given in electronic format in accordance with a separate instruction given by Fingrid System Oy. The bids shall include information on the capacity to be regulated (MW), its price (EUR/MWh) and the transmission area where the offered resource is located (north or south of 64° latitude).

The ordered regulation shall be capable of being supplied during the entire hour of use in question. The minimum capacity of one bid is 10 MW. All the offered regulations shall be capable of being implemented up to their full capacity within 10 minutes from the order. A

corresponding time is valid when the regulation is finished. Bids can be given, changed or cancelled constantly starting from the calendar day preceding the hour of use under offer. The bids can be changed up to 30 minutes before the beginning of the particular hour of use. After this, they become binding [15].

3.1.5.1.3 Handling of regulation bids and principles for ordering of regulation

1. Price order

   For each hour of use, the up-regulation bids are put into order on the principle of the cheapest bid first, and the down-regulation bids on the principle of the most expensive bid first. Bids of the same price are put in chronological order, i.e. earlier bids first.

2. Ordering of regulation

   For normal balance management, Fingrid System Oy accepts the bids in the price order. However, Fingrid System Oy can in exceptional cases prioritise a bid with a large capacity or one that can be implemented quickly. A regulation order is placed by telephone, and the power, price and the starting moment of regulation shall be given in the order. The starting moment of regulation is agreed upon with an accuracy of minutes. The ending of regulation is also reported by telephone. If no report on the ending of regulation is given, the regulation is deemed to end at the end of the hour. If the regulation is requested earlier than five minutes before the desired starting moment, the regulation is deemed to have started from the moment of time stated by Fingrid System Oy in the order. If the regulation is requested to be started immediately, the regulation is deemed to have started after five minutes from the placing of the regulation request. Fingrid System Oy and the party that has made the regulation bid can agree on the beginning of regulation even faster, situation allowing.

When placing the regulation order, balance provider shall specify the resource with which the regulation is carried out and the starting moment of regulation. If it becomes evident during the hour of use that the offered regulation cannot be implemented due to a disturbance or other similar reason or that it can only be implemented partially; the possessor of the resource has to immediately inform Fingrid System Oy of this. In this case, the regulation is registered only insofar as it is carried out [15].

3.1.5.1.4 Statement of regulation energies and confirmation of orders

Delivery of electric energy between Fingrid System Oy and balance provider is created in the hourly energy balance of balance provider because of Fingrid System Oy's use of regulation electricity. The volume of hourly energy caused by the use of this so-called *regulation power* is calculated as the product of regulation power and the time of use. Regulation power orders have an effect on the balance of the party, and they are automatically taken into account in the balance settlement of balance provider. Fingrid System Oy reports the ordered regulations directly to the national balance settlement, so balance provider carrying out the regulation does not have to report them.

If a player has submitted a regulation bid to the regulation power market and the bid has not yet been activated, the player has the right to record a volume of electricity corresponding to the bid from Fingrid System Oy at the price stated in the bid. However, in the case of up-regulation bid, the price is at least the basic price for the hour, and in the case of down-regulation bid, the price is at the most the basic price for the hour. This right is valid until the regulation is activated [15].

3.1.5.1.5 Hour change regulation

In order to reduce the problems encountered at the turn of the hour, Fingrid System Oy reserves the right to transfer the planned regulations in generation to begin 15 minutes before or after the planned moment. The balance error resulting from this transfer is corrected by means of electricity trading priced accordingly, where the electricity volume corresponds to the volume of electricity generated or not generated as a result of the transfer. For a justified reason, Balance provider has the right to refuse the implementation of hour change regulation.

3.1.5.1.6 Reserve power deliveries

If disturbance situations take place in generation included in the balance of balance provider, Balance provider is entitled to purchase from Fingrid System Oy a volume of reserve power corresponding to the loss of generation capacity for the disturbance hour and eight hours immediately following the disturbance hour. Reserve power deliveries require that Fingrid System Oy has the real-time status and power information on the target in its own system and that the hourly generation forecast on the target in question is included as a separate item in the plan for the following calendar day, given by the party. In conjunction with disturbance

situations in shared power plants, the balance provider in whose balance the shared power plant is included reports to Fingrid System Oy the volume of shareholder-specific energy volume which each shareholder is entitled to purchase from it.

The volume of reserve power trading is agreed between Fingrid System Oy and balance provider separately for the hour of use, and it is entered directly in the national balance settlement [15].

3.2 THE ELECTRICITY MARKET IN GREAT BRITAIN

3.2.1 The Electricity scenario in United Kingdom

From nationalisation in 1947 until 1990, the Central Electricity Generating Board (CEGB) operated all generation and distribution facilities in England and Wales as a vertically integrated statutory monopoly. Power was supplied to twelve state-owned regional distribution companies, area boards, which in turn distributed power to all customers within their service territories. Area board actions were tightly co-ordinated with the CEGB, so that the resulting behaviour was little different from that to be expected from a single fully integrated public corporation.

On 31 March 1990, the electricity industry was restructured and then privatised under the terms of the Electricity Act 1989. The National Grid Company (NGC) plc assumed ownership and control of the transmission system and joint ownership of the interconnectors with Scotland and France, together with the two pumped storage stations in North Wales, but these stations were subsequently sold off.

Since 1990, the electricity industry in the United Kingdom has undergone two radical changes: the privatisation of almost all the electricity companies and the introduction of competition. The change of ownership in itself had a major impact on an industry which spent some 40 years in the public sector. At the same time, the entire industry was fundamentally restructured. This was done with a number of objectives in mind, namely the creation of a competitive electricity market; financial independence from Government; wider share ownership; and a greater involvement for employees in the future success of the companies they work for [17].

The most novel feature of the reform was the introduction of customer choice, so that customers were able for the first time to change their electricity supplier. Another innovation was the separation of the monopoly elements of the business (transmission and distribution), from those elements, which would be subject to competition (generation and supply). There are three separate electricity systems in the United Kingdom: England and Wales, Scotland and Northern Ireland. There are some differences of structure between the three markets, but the same principles apply.

The CEGB's remaining non-nuclear generating stations were transferred to National Power and PowerGen, while its nuclear generating stations were transferred to Nuclear Electric. Subsequently, the new PWR (Pressurised Water Reactor) and AGR (Advanced Gas Reactor) nuclear power stations of Nuclear Electric and Scottish Nuclear were combined and a new company called British Energy created. The old Magnox nuclear power stations were left in government ownership as Magnox Electric and then acquired by BNFL (British Nuclear Fuels Limited).

The property, rights and liabilities of the 12 area electricity boards, including the local distribution systems, were transferred to the 12 Regional Electricity Companies, which are still in existence today although under different ownership. The Regional Electricity Companies were the main shareholders in National Grid until the company was floated on the stock exchange in December 1995.

In Scotland, vertical integration was maintained in the new structure with the creation of Scottish Power and Scottish Hydro-Electric, (the latter has since merged with Southern Electric to become Scottish and Southern Energy). As in England and Wales, nuclear generation was assigned to a separate company, Scottish Nuclear, which became part of British Energy in 1996.

In Northern Ireland, the four power stations were purchased by a number of competing generators in 1992. Northern Ireland Electricity (NIE) became responsible for transmission, distribution and supply and was successfully floated on the Stock Exchange in 1993. A further reorganisation carried out by NIE in 1998 resulted in the creation of a holding company, Viridian Group.

The 1989 Electricity Act also created a system of independent regulation, headed by the Director General of Electricity Supply (DGES), covering England, Wales and Scotland. The regulator's principal roles are to ensure that competition develops smoothly and effectively and that, where competition is inappropriate, adequate safeguards are in place to protect customers. In 1999 the regulatory offices for electricity and gas (Offer and Ofgas) were merged to form the Office of Gas and Electricity Markets (Ofgem). Ofgem is the Office of the Gas and Electricity Markets, regulating the gas and electricity industries in Great Britain. Ofgem is governed by an authority and its powers are provided for under the Gas Act 1986,

the Electricity Act 1989 and the Utilities Act 2000. Northern Ireland has its own regulatory body, the Office for the Regulation of Electricity and Gas (Ofreg) [18].

3.2.1.1 THE COMPETITIVE MARKET

Before the year 2000, any generator exporting more than 50 MW on to the system is required to hold a generation licence and to trade its output via an open commodity market, the Electricity Pool. The Pool is a simple name for what is, in effect, a very complex trading mechanism. Set up in about a year, it has seen continuous evolution and development.

Essentially, each generating unit had to declare by 10.00 hours each day its availability to the market, together with the price at which it is prepared to generate, for each and every half hour of the following day. The units are then called to generate by National Grid in ascending order of price. The most expensive unit used establishes the System Marginal Price (SMP), which all other generators supplying electricity receive for that half hour. There was an additional pricing mechanism designed to provide an incentive for the provision of generating capacity. The resulting Pool Purchase Price (PPP) was calculated the day before trading and was published the following day in the Financial Times.

Suppliers purchasing electricity via the Pool buy at the Pool Selling Price (PSP), which is the sum of the Pool Purchase Price and a further element known as Uplift. This incorporates charges for ancillary services that ensure that the system remains stable and secure.

This form of virtual real-time pricing inevitably tends to produce volatility in prices and either buyers or sellers do not necessarily welcome this. To overcome this, the Pool has been overlaid with both short and long term contracts to make capacity and energy prices more predictable for both customers and generators. These so-called Contracts for Differences (CfDs) typically involve an agreed 'strike price' (an agreed price per kWh) for a specified quantity of electricity and a specified period of time. If the Pool price for selling electricity is below the agreed 'strike price' for any half hour, the supplier will pay the generator the difference between the two prices. Similarly, if the 'strike price' is below the Pool price, the generator will pay the difference to the supplier. CfDs are essentially financial instruments, the main purpose of which is to hedge risk [18].

Later, in the year 2000 New wholesale electricity trading arrangements (NETA) for England & Wales were introduced. In the NETA design the old day- ahead pool based on a co-ordinated spot market with a market- clearing price was replaced by a three- and- a half- hour ahead balancing system with a complex pricing scheme that features pay- as- bid mechanism with rules intended to penalise imbalances. The governance arrangements that supported NETA include the establishment of a *Balancing and Settlement Code* (BSC, or Code) Panel, to oversee the Code and to progress modifications to it, and a company, BSC Co, to provide or procure a range of operational and administrative services, both directly and through contracts with service providers. The company was given powers under the Code to recover its costs from Trading Parties [19].

ELEXON is the Balancing and Settlement Code Company (BSC Co) defined and created by the Balancing and Settlement Code (BSC or 'the Code'). All licensed electricity companies are obliged to sign the Code. The Code places obligations on ELEXON. ELEXON procures, manages and operates services and systems, which enable the balancing and imbalance settlement of the wholesale electricity market and retail competition in electricity supply.

3.2.1.2 NEW ELECTRICITY TRADING ARRANGEMENTS

In summary, the existing mandatory Pool, established through the Pooling and Settlement Agreement, was replaced with new trading arrangements designed to be more efficient and to provide greater choice to market participants, while maintaining the operation of a secure and reliable electricity system. The new arrangements include:

- forward and futures markets (including short-term power exchanges) which evolve in response to the requirements of participants and allow contracts for electricity to be struck over timescales ranging from several years ahead to on-the-day markets;
- a Balancing Mechanism in which the NGC, as system operator, accepts offers of and bids for electricity close to real time to enable it to balance the system;
- a Settlement Process for charging participants whose contracted positions do not match their metered volumes of electricity, for the settlement of accepted Balancing Mechanism offers and bids and for clearing certain other costs of balancing the system.

The basic principle of NETA is that those wishing to buy and sell electricity should be able to enter into freely negotiated contracts in order to do so. Under the new arrangements, it is expected that bulk electricity will be traded forwards and on one or more power exchanges

through bilateral contracts. Those buying and selling electricity on such exchanges, and through bilateral contracts, are likely to include not only generators and suppliers (who produce or whose customers consume physical quantities of electrical energy), but also non-physical traders [19].

The role of the NETA Programme is not to dictate how energy will be bought or sold ahead of real time. Instead, it is to provide mechanisms for certain centralised activities that cannot reasonably be expected to be handled by decentralised markets namely:

- the real-time balancing of the transmission system; and
- the calculation and settlement of imbalances which will inevitably arise between contractual and physical positions.

Figure 3.13 shows the range of trading types that might be expected in relation to any trading period, and those elements that will be provided centrally by the NETA Programme.

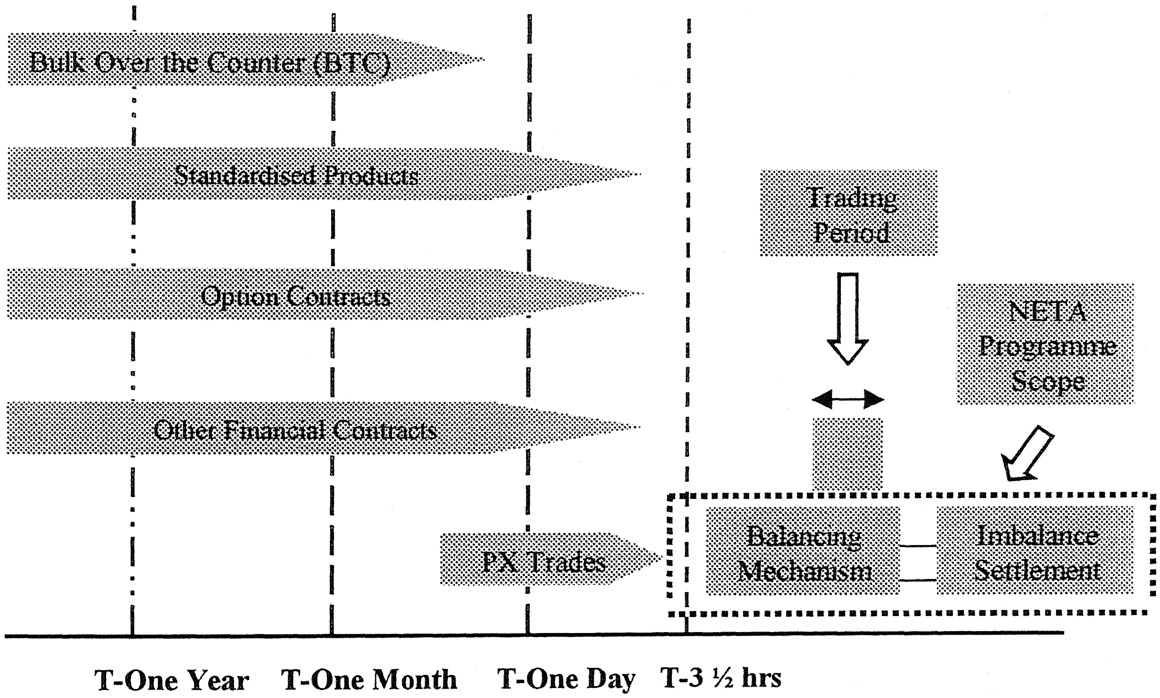


Fig 3.13: Trading Under the New Arrangements

The trading periods of one-year and one-month consider the same contracts and trading while for the one-day trading period, the BTC trading is not considered but utilises the power exchange (PX) trades. In the three-and-a-half trading period, the balancing mechanism and imbalance settlement of the NETA design starts functioning [20].

3.2.2 The Balancing and Settlement code

The arrangements for the Balancing Mechanism and the Settlement Process are contained in a Balancing and Settlement Code. The Code is maintained by NGC under a new condition in its transmission licence. Licensees, and those other parties who choose to participate, will enter into a short multilateral framework agreement giving the BSC contractual force. The wholesale market after the introduction of NETA can conveniently be divided into four areas:

1. Forwards and futures market
2. Power exchange
3. Balancing Mechanism and
4. Settlements.

As seen from the Fig 3.14, the four areas of the market perform their respective operations in the time limits specified below. The functioning of each of the areas are explained in detail in the next section.

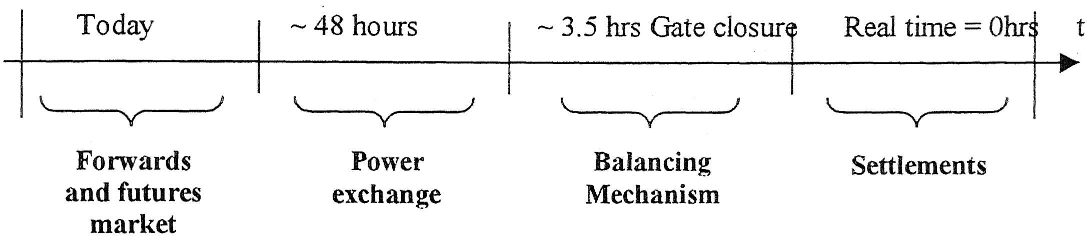


Fig 3.14: The Wholesale market

3.2.2.1 Forwards and futures market

This is the market from today until the day ahead in advance of real time of delivery. The contracts involved are bilateral (two-way) trades of electricity for physical delivery are conducted, either OTC (over the counter), via brokers or on futures exchanges, at an agreed price between interested parties; buyers (e.g. electricity supply companies) and sellers (e.g. generators). Suppliers make estimates of their demand based upon contracted loads and sales expectations. They will use this information to contract with generators to meet these basic requirements.

3.2.2.2 Power exchange

This is the market from approximately (~) 48 hours in advance until 4 hours in advance of real time of delivery. The contracts here done are standard trades that are quoted on exchanges at bid price (to purchase) and offer price (to sell). The power exchange offers the opportunity for interested parties to 'fine tune' their positions four hours ahead of real time based on more up to date information and half hourly prices. The standard contract period in this market is each individual half-hour within a day, which can be combined by participants to construct other

periods when prices are available. The power exchange closes four hours in advance of real time.

Approximately 24 hours before physical delivery, suppliers begin to fine-tune their positions. They need to buy or sell electricity to cover any excess or shortfall between their actual position and that covered by the contracts in the Forwards and Futures market. Suppliers must declare their positions by making *Physical Notifications* (PN), up to 3.5 hours before physical delivery - this is known as Gate Closure - when a *Final Physical Notification* (FPN) is submitted. It is on the basis of this FPN that Settlements will be undertaken. Alongside PN's, generators and suppliers can also make Balancing Mechanism Offers to help secure the system. It is here that customers with load management or self-generation abilities can benefit under NETA [21].

The terms of the balancing mechanism and imbalance settlement arrangements and related governance, which have been developed in the NETA programme and are set out in the Code, are as follows.

3.2.2.3 Balancing mechanism

1. Generators and suppliers (and persons trading over interconnectors) can submit bids and offers to NGC, to increase or decrease their levels of production or consumption at different points in any half-hour settlement period;
2. NGC can accept such bids and offers, in order to balance generation and demand, or manage constraints on the system;
3. A party submitting a bid or offer that NGC accepts will pay or be paid the bid or offer price for the quantity of electricity for which it was accepted [19].

Under NETA, participants will be able to self-schedule, in that they will be responsible for determining what levels of output and/or consumption they will undertake. In such an arrangement, a mechanism is required for adjusting, in real time, the intended levels of generation and demand. This is for two reasons. First, it is likely that the total output of generation will not automatically match the total consumption of customers at any given time. This is because some parties may not have exactly predicted their actual operating position, weather and other factors may alter expected demand nationally or regionally, some generation may not be available due to unanticipated faults and so on. Secondly, for a number

of technical reasons, it may be necessary for the system operator to adjust the level of production, or consumption, of individual generators or customers away from the level at which the generator or demand would otherwise wish to operate. Such adjustments will ensure secure operation of the transmission system.

To help enable production and consumption to be kept in equilibrium in real time, NETA provides for the provision of a 'Balancing Mechanism'. Close to, and in real time, NGC, in its System Operator role, will determine what actions need to be taken to maintain the required national and local balances of generation and consumption. It will then accept relevant *bids and offers* placed in the Balancing Mechanism to achieve this. Participation in the Balancing Mechanism will be open to all generators and those on the demand side who are willing to change their output or consumption from that planned, at whatever price they choose to offer or bid into the mechanism, and who have the physical capability to respond within the relatively short time horizons that NGC will require [20].

This can be explained as: For example, in a 'two-participant market', a generator sells 100 MWh of contracts to a supplier for a particular half-hour. The generator and the supplier post FPNs of 100 MWh and –100 MWh respectively. In addition, the generator submits a bid to reduce generation by 15 MWh at £5/MWh. If the demand is indeed lower than expected (say –90 MWh), then the system operator will accept the generator's bid and the generator will pay 10*5 = £50 to reduce its own generation. The supplier, which is long by 100 – 90 = 10 MWh, will spill on to the system and receive the system sell price of £5/MWh for the 10 MWh contracted demand it does not take. NGC will also have the ability to contract for balancing services ahead of time in order to ensure that sufficient flexibility exists in real time for system balancing purposes.

3.2.2.3.1 Day Ahead and within Day Balancing Mechanism

In this process (Fig 3.15), by 9.00 hours each day, the day ahead demand forecast covering the period 05:00 hours day ahead to 05:00 hours day ahead + 1 are published and by 11:00 hours the PN and other data from all *Balancing Mechanism* (BM) units covering the same period are received. Using the submitted PN data, demand forecast and planned transmission outage information, security analysis studies to verify system security are undertaken. For each half hour period from 05:00 hours day ahead to 05:00 hours day ahead + 1 the sum of BM Units called *Maximum Export Limit* (MEL) is calculated based on the 11:00 hours PN submission and the *system plant margin* for each half-hour period is then calculated. By 12:00 hours each

day the total system plant margin data to the market for the period 05:00 hours day ahead to 05:00 hours day ahead + 1 is issued. If found required, Balancing Services contracts are called off to ensure, inter alia, that BM Units required to maintain system security are available for selection in the Balancing Mechanism.

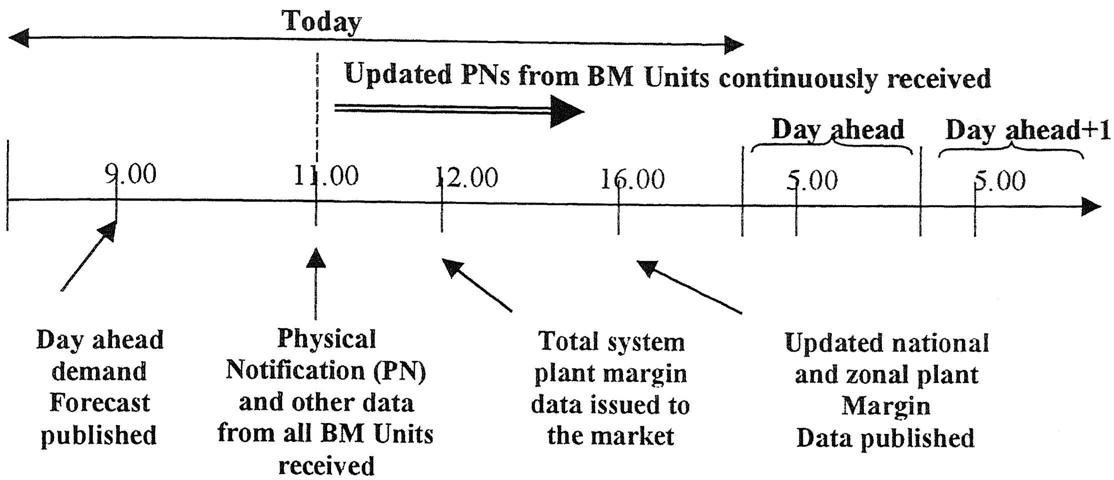


Fig 3.15: Day balancing mechanism

The updated PNs from BM Units are received continuously after 11.00 hours. Using this updated data, the national plant margin data along with zonal margin data are published by 16:00 hours. For within Day balancing, at gate closure the PN data will become FPN data and *Bid/Offer* prices and volumes for those BM Units wishing to actively participate in the Balancing Mechanism are received. Using the revised demand forecast and validated FPN and Bid/Offer data, the system is balanced (on a minute by minute basis) through the purchase of Balancing Services on an economic basis [22].

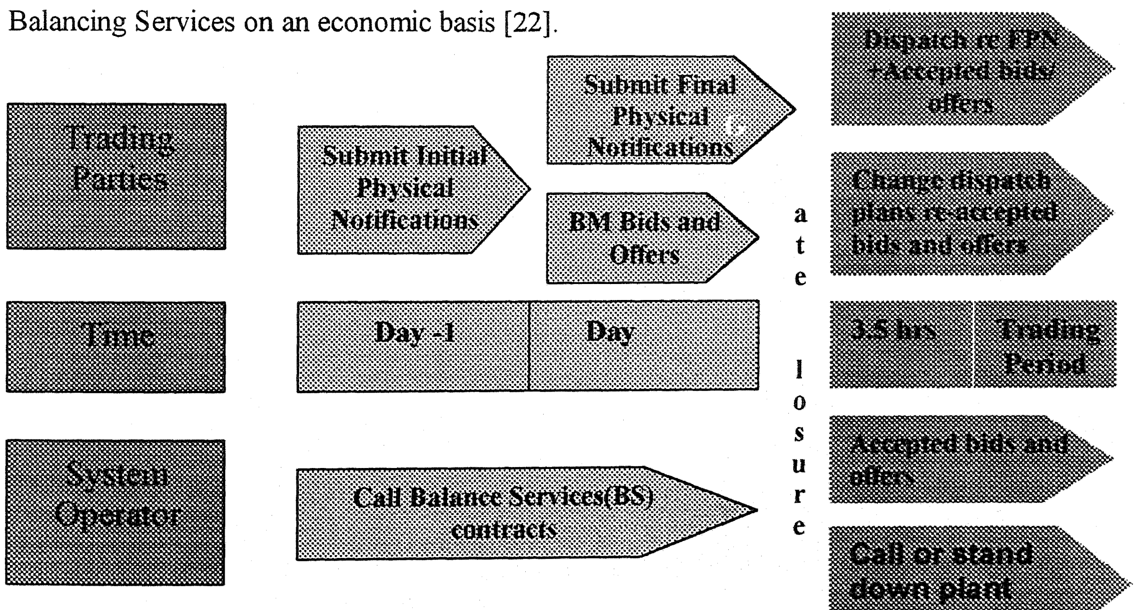


Fig 3.16: Balancing the System

The Fig 3.16 shows the same mechanism as explained above along with the principal elements that contribute to system balancing with the trading parties and System operator doing their respective jobs in the time zones of the trading periods mentioned.

3.2.2.4 Price Settlement

In practice, generators may physically generate more or less electricity than they have sold. the customers of suppliers may consume more or less energy than their supplier has purchased on their behalf, and traders of electricity may buy more or less energy than they have sold. In such circumstances, the central NETA systems are designed to measure these surpluses and deficits (or imbalances) and to determine the prices at which they are to be settled in order to send out invoices and payments for them. This process of calculating and settling imbalance volumes is referred to as 'Imbalance Settlement'.

Fig 3.17, shows the principal steps in the settlement process that are being discussed, and also a about the various elements that are settled during settlement [20].

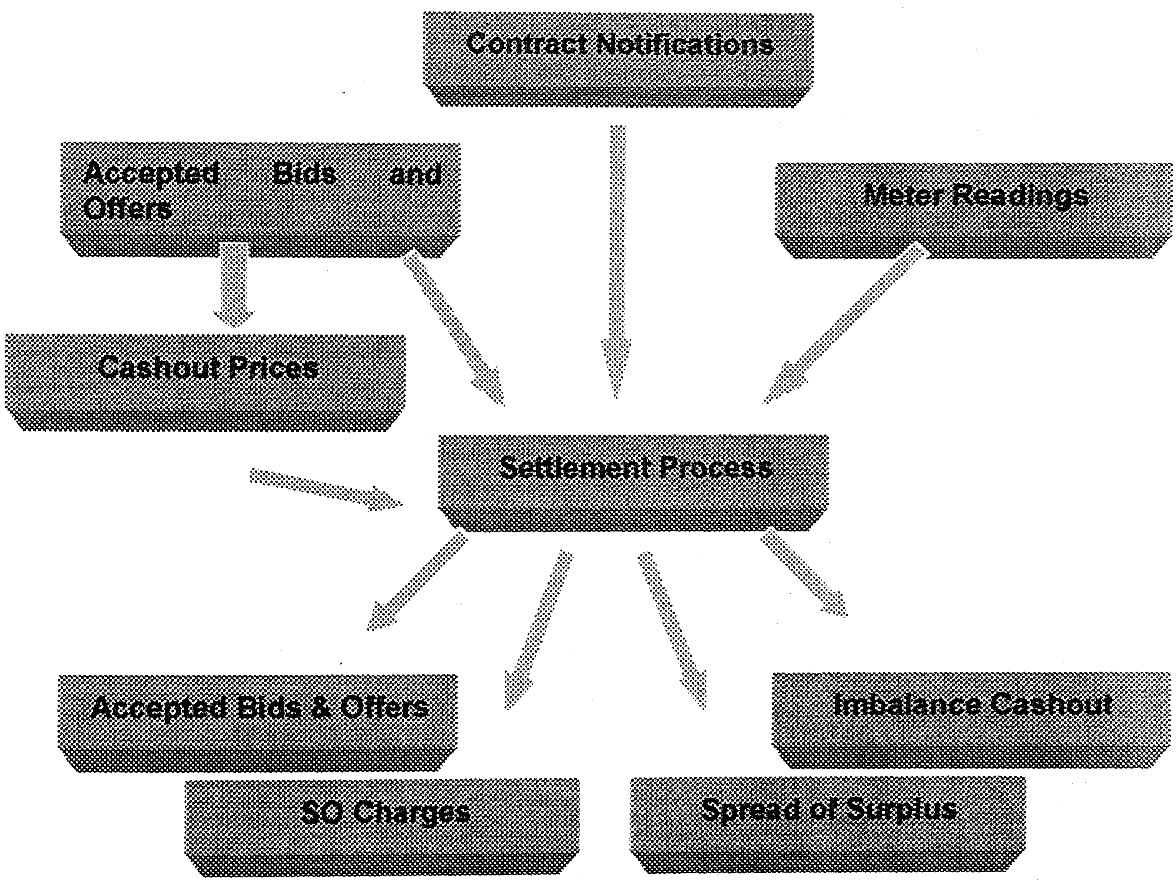


Fig 3.17: Price Settlement

In the settlement process,

1. Generators and suppliers (and persons trading over interconnectors, and others) can enter into bilateral contracts for sale and purchase of electricity in any settlement period. These contracts are formed outside the BSC;
2. Parties to the BSC may notify under the BSC the contract volumes for any settlement period under such contracts;
3. The imbalance, for each party, between its metered generation or demand (or allocated metered flows at interconnectors) and its net aggregate contract position, adjusted to take account of accepted bids or offers in the balancing mechanism, is determined for each settlement period and cashed-out at an imbalance price calculated under the BSC. The imbalance price reflects the weighted average cost of accepted bids or offers, according to whether the imbalance is positive or negative (but excluding bids and offers assumed to have been accepted to manage transmission constraints), in the balancing mechanism for the relevant settlement period.

This process also settles those trades accepted in the Balancing Mechanism as well as various System Operator charges. The process then spreads the surplus that arises from having different imbalance prices to those who need to pay for a shortfall of energy, as opposed to those who are in the opposite position and who need to be paid for surplus energy. Imbalance volumes and imbalance prices will be calculated on a half-hourly basis, and settled on a daily basis, on average, 29 days in arrears [20].

3.3 THE ELECTRICITY MARKET IN GERMANY

On the basis of the new German energy law (Energiewirtschaftsgesetzt), the German power market was liberalised in April 1998 and the territorial monopolies were abolished [23]. The German Electricity Association (VDEW) is the association for supply of the electricity in the Federal Republic of Germany. Either directly affiliated or indirectly aligned via regional associations, its members include all the large, virtually all the medium-sized and most of the smaller companies involved in the public supply of electricity - altogether more than 750 suppliers from a total of approx. 1,000 in Germany. The utility market is highly fragmented in Germany, with about 70 regional utilities and 900 municipal utilities, which together account for about 20% of power generation and about two-thirds of distribution. Merger and acquisition activity also is re-shaping these utilities, with about 15 mergers among 40 companies in 1999.

Coal accounted for 46% of domestic energy production in 1998, nuclear power 31%, natural gas 14%, renewable sources 6%, and oil 3%. However, oil accounted for 44% of consumption. Germany has Europe's largest electricity market. In 1998, Germany generated 525.4 billion kilowatt hours of electricity, two-thirds of which came from fossil fuels (mostly coal), with the other third coming mostly from nuclear power along with small amounts of hydropower and other renewable sources. The country was a net electricity exporter, consuming only 488.0 bkwh. Germany had about 2,800 power plants and considerable excess generation capacity [24].

The energy market in Germany was opened to competition in 1998. It is the fastest to open up, with immediate 100% full customer choice, though UK and parts of Scandinavia were opened earlier. There is no independent system operator or regulator, but rather six transmission systems operators and several hundred (almost one thousand) distribution network (grid) operators acting in the spirit of co-operation and self-regulation. A system of self-regulation through various existing energy laws and most importantly the so-called Associations' Agreements (currently electricity is on its second, Verbändevereiningung II-VV II) govern the rules of the game. Drafted and agreed by three industry associations, the Associations' Agreements are private, voluntary framework agreements for the use of grid. As such, these gentlemen's agreements have no legal status. They can be binding only if the participating companies conclude contracts that take these agreements into account. The three parties Federal Association of Germany (BDI - Bundesverband der Deutschen Industrie e.V., Berlin),

Association for the Industrial Energy and Power Industry (VIK - Verband der Industriellen Energie und Kraftwirtschaft e.V., Essen), and German Electricity Association (VDEW - Vereinigung Deutscher Elektrizita:tswerke e.V., Frankfurt/Main) represent mainly the industrial customers and the grid owners/operators, but not households or other diverse interests, especially newcomers to this market. The six transmission systems operators have control over 85% of power generation, with the remaining 15% in the control of the municipalities with co-generation. Lacking a regulator and independent systems operator has not stopped Germany from establishing two electricity exchanges: Frankfurt-based European Energy Exchange (EEX) and Leipzig Power Exchange (LPX) [25].

Six major electricity generation companies dominate the German market now, accounting for about 80% of generation. They are Bewag AG (Berlin), EnBW Die Energie AG (Karlsruhe), E.ON Energie (Munich), Hamburgische Electricitäts-Werke AG (HEW-Hamburg), RWE Power (Essen) and VEAG Vereinigte Energiewerke AG (Berlin). Major mergers reshaped the industry, potentially reducing the number of major players from six to three in the near future. RWE, the largest energy company in Germany, has acquired VEW, the country's six-largest electricity producer. Preussen Elektra AG of Veba, Germany's second-largest power company, merged in June 2000 with Bayernwerk AG of Viag, the third-largest, to create E-ON. The newly merged companies will be Europe's third- (RWE) and fourth-largest (Eon) electricity companies, behind the French state company EdF and Italy's ENEL. Apart from being electricity producers, companies like RWE take care of the regulating power (control energy) for safe and reliable operation of their own networks. This is discussed in the section concerning the balance of power in the balancing market.

In efforts to meet antitrust regulation, the four merging companies will sell their combined 81% share of Veag, which had been the fifth-largest electric company to U.S.-based NRG Energy, which mines lignite in Germany, and Germany's former fourth-largest company, EnBW, will bid jointly for control of Veag.

The DVG (Deutsche Verbundgesellschaft) is the association of the German transmission system operators with responsibility for the system. Through the DVG, the member companies concentrate their activities concerning transmission systems with a view to combining the benefits of decentralised organisation with the advantages of joint action. They

are responsible for the planning and operation of their transmission equipment. All functions relating to interconnected systems operation are co-ordinated in the DVG.

3.3.1 The Spot Electricity market

The German electricity market is the largest and one of the most promising power markets in Europe. Three power exchanges offer their service in Germany: the Amsterdam Power Exchange (APX), the Leipzig Power Exchange (LPX) and the European Energy Exchange (EEX). While LPX and EEX are German initiatives which became operational later, APX started a German spot market on May 3, 2000.The German spot electricity market is strongly influenced by the implementation of the new Association Agreement on 1 January 2000. This new agreement was developed to be able to facilitate a spot market.

The spot market in Germany is characterised by a point tariff for transmission pricing. Germany was previously divided into two trading zones, each consisting of several electrical control areas. Trade between the two zones was subjected to a transmission fee to the System Operators. The "Northern" zone comprised the transmission systems of VEAG, PreussenElektra Netz GmbH & Co. KG, VEW Energie AG, HEW AG and Bewag AG. The "Southern" zone comprised of the systems of EnBW Transportnetze AG, RWE Energie AG, Bayernwerk Netz GmbH. All system users are allocated to one of the two zones depending on their point of connection to the system. For electricity exchanged between zones, transportation charges of 0.25 pfenning/kWh was payable on the net amount exchanged in each quarter-hour period. The net amount was calculated for each balancing group Analogous charges are levied at the interconnection points of the German system to and from neighbouring countries [27]. But now only one zone prevails in the whole of Germany.

Transmission Tariffs are 'point related', i.e. they are independent of the financial transaction. Only input/exports and trade between the two trading zones is subject to the additional transmission component. During transmission, congestion System Operators have to relieve congestions in the network. Structural constraints may be published by the network operators and may lead to a rejection of a transmission request. The involved parties settle financial contracts. Imbalances are settled by the System Operators. Settlement is based on 'balancing accounts' similar to the established settlement structure in Scandinavia (imbalance is the difference between the metered and the scheduled volume, aggregated in a balancing account). Due to retail competition small-scale consumer, for which hourly metering would commercially not be feasible, can be profiled. The respective network operator determines the

profiles. Settlement of profiles is possible according to the 'analytical method' or the 'synthetical methods', subject to the preference of the network operator.

The Leipzig Power Exchange (LPX) is modelled on the example of ElSpot, the Nordic spot market operated by Nord Pool. The spot market is a day-ahead market with hourly contracts to be delivered the next day. Trade is executed one day ahead of the day of delivery. The spot market concept is based on bids for purchase and sale concerning hourly power contracts for the 24 hours of the following day. Price determination is based on an auction trade system where hourly-based prices are calculated after all bids for all hours have been received during a fixed period of time. If there are no capacity constraints, there will be only one price for the total market area - the unconstrained Market Clearing Price (MCP). The price mechanism can also be used to relieve constraints in the main transmission grid. The total market is separated into bid areas. A *bid area* is either one TSO-area or consists of two (or more) connected TSO-areas where the TSOs involved have agreed to co-operate in case of activities at the interface towards LPX. Bid areas may form separate price areas in case of constraints. LPX intends to allocate these costs over its participants in proportion to their traded volumes in the direction of the aggregated flow. A futures market followed as soon as the spot market provided a reliable reference price.

The Amsterdam Power Exchange (APX) also performs only one auction. Like the spot market of LPX, the APX is a two-sided auction or market-clearing model that offers hourly contracts one day ahead of delivery. APX offers the two spot markets through the same trading system. APX offers a Forward Market to its participants via a Bulletin board Trading System (BTS). This is a system for bilateral transactions, on which participants can place offers and bids for standardised contracts. Participants conclude a transaction by choosing one of the published bids. Settlement is done bilaterally without the involvement of APX. New market products are planned, such as an adjustment market or hour-ahead market (HAM) and a futures market.

On August 8th 2000, the European Energy Exchange (EEX) commenced day ahead trading with standardised products on the EEX Spot Market. The Futures Market started on March 1st. 2001. Conceptualised and majority-owned by European traders, grid operators, energy suppliers and financial institutions, EEX is the only European Energy Exchange to offer products designed in close co-operation with the energy industry for the energy industry. The

EEX spot market distinguishes three types of contracts: blocks for peak-hours, blocks for all hours and hourly contracts. The block contracts are traded in three phases:

- a first auction at 8 a.m.
- a four hour period of continuous trade, starting with all open bids and offers
- a closing auction at noon

Both auctions are two-sided with one market clearing price. The hourly contracts are traded at a separate auction at 10 a.m., comparable to the APX and LPX markets. The futures market started in the fourth quarter of 2000 [23].

The physical settlement of power takes place with each market participant required to nominate a balancing group co-ordinator (Bilanzkreisverantwortlicher BKV) who is responsible for the participants' compliance with its physical obligations. A *balancing group* consists of an arbitrary number of injection and/or withdrawal points (usually metering points for generating units or power stations, and loads) within a control area. The assignment of each injection and withdrawal point shall be specified to the system operator responsible for the supply connection, and must therefore be exactly defined. The system operator in charge is responsible for the reading of metering values. Taking account of the common minimum requirements for balancing group managers (BGMs), the TSO shall conclude a contract with a BGM for each balancing group. The BGM represents the interface between system users and TSOs. A BGM is responsible for the compensation of differences between procurement and delivery per period of accounting (15 minute mean power values) within his balancing group. The instantaneous settlement of the power balance within the control area shall be incumbent on the TSO [2].

3.3.2 The Balancing power market

Maintaining the principal requirements upon the primary, secondary and tertiary control does the balance between the production and consumption of electricity from the UCTE`s perspective to Germany as the control block and applied by analogy to the control areas within Germany. RWE Energie AG is the German Control block leader and therefore holds overall responsibility with respect to other members of the UCTE synchronous network. The frequency is maintained in the range of ± 200 mHz

RWE Net AG, the network company of RWE Group, needs approx. 2,000 MW of control energy for the safe and reliable operation of its network. This control energy ensures a balance

between generation and consumption at all times. A distinction is made between the following types of control energy: primary control power, secondary control power and minute reserve. RWE Net responsible for system management according to the relevant needs and purposes uses the control energy. For this, bidders for the different types of control energy participate in a pre-qualification procedure. The various types of control energy are procured by means of competitive tendering in a liberalised electricity market. On the basis of all bids submitted for the respective period, RWE Net will award the contracts after having examined the bids from economic and technical perspectives using a form of election process [26].

The control tasks of *Primary* and *Secondary regulation* maintain the balance responsibility, which means that the company is financially responsible for the production and consumption of power always being in balance within the company's commitment, and so has to provide (pay for) the sufficient *regulating power.* The *primary control reserve* to be maintained by each control area must be able to be activated within 15-30 seconds in the event of a disturbance between 1500 and 3000 MW. The maximum primary reserve that RWE Net allocates to each unit is ± 330 MW. The *secondary control power* may be used only for compensation of the instantaneous total system deviation. Restoration of the frequency and the interchange power to the set point value must begin within 30 seconds and must be completed within 15 minutes. In production units of RWE Net, which are involved in the secondary regulation, at least a secondary reserve volume of ± 30 MW must be available.

When failure of the largest generating unit is not prevented by the secondary control reserve, *minutes reserve* is utilised in addition, which need not be maintained within the control area in question. RWE Net keeps an amount of ± 30 MW in a state of readiness to transfer upon a request for each unit to make of total from –550 MW to +700 MW presently. All the three regulating reserves do not operate for the same failure; rather, the reserve switches from one to another so that the former is ready for the next regulation or balancing power. Each generating unit has to declare by 14.30 hours each day its availability to the market, together with the price at which it is prepared to generate, for each and every one hour of the following day [2].

System users with electricity generation order *reserve system capacity* from the system operator separately from subscribed system capacity. The reserve system capacity has a defined maximum and cannot be exercised for more than 600 hours per year. The user

determines the level of the subscribed reserve system capacity; it can be zero also. The subscribed reserve system capacity has to be paid regardless of the level at which it is being used. A separate reduction factor is defined for the use of reserve system capacity and is defined as follows: for an use of zero to 200 hours, 0.25, from 200 to 400 hours, 0.30, for 400 to 600 hours, 0.35. The start, expected duration and end of the use of reserve system capacity shall be reported to the system operator immediately and must be documented upon request. The time period for which reserve system capacity used is determined by the capacity exceeding the annual peak capacity during normal use, up to the reserve system capacity. If the reserve system capacity is used for more than 600 hours, instead the general coincidence function of the given system operator will be applied for the entire supply; however, the coincidence factor shall not be less than 0.35. If actual reserve system capacity used exceeds subscribed reserve system capacity by more than 10%, the capacity in excess of 10% can be charged at the full annual capacity price (at a coincidence factor of 1.0) [27].

3.3.2.1 Tolerance band

To ensure secure system operation and the resulting need to continuously balance feed-in and extraction per balance group, the system operators contract for normal and reserve capacity with generators and with end users who have interruptible load. Differences between the feed-in and extraction within a ¼-hour interval measurement period are deemed to be non-attributable and are charged for as part of system services charges.

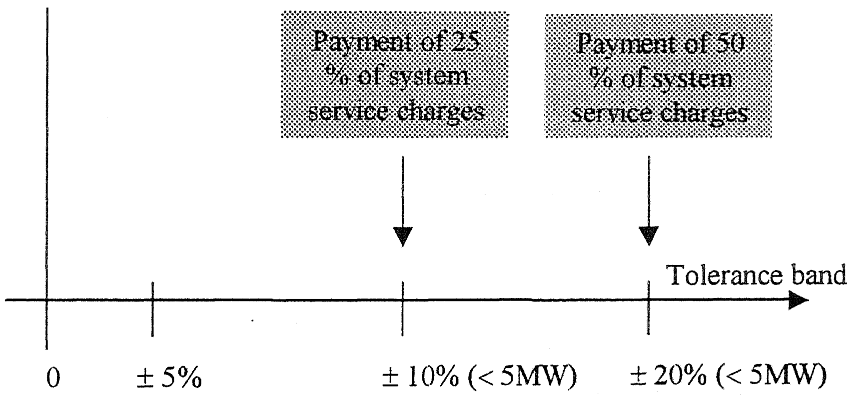


Fig 3.18: Tolerance band and the system service charges

The standard tolerance band is +/- 5% of the reference value. The reference value is defined as the value of the cumulative simultaneous peak loads at all the extraction points in a balancing group within a control area, within the 15-minute measuring periods, measured over the course of a month. The costs of the standard 5% tolerance band are included in the use of system charge. Also, it is possible to subscribe to an extended tolerance band of up to 20%.

but this must not exceed the maximum of +/- 5 MW. If a 20% tolerance band is chosen, the balance group manager is required to pay 50% of the system service charges. For a tolerance band of 10% the balancing group manager must pay 25% of the system service charges [2].

Pricing of balancing group differences

1. Within the tolerance band: Within the agreed tolerance bands, compensation in kind between 2 tariff zones is possible. To this end, the deviations occurring in the two tariff zones are netted separately. The account balance at the end of a settlement period (Monday 00.00 a.m. - Sunday 12.00 p.m.) is valued as follows:

   - In the high tariff zone, up to 6 full-load hours (relative to the reference value of the tolerance band) may be transferred to the following settlement period. For the low tariff zone, 4 full-load hours may be transferred to the following settlement period. Account imbalances over and above that level are charged or paid for by the TSO at asymmetrical market prices (per kWh). Deficits will be charged for at x and surpluses will be credited for at y.

2. Outside the tolerance band: In the event of consumption over and above the upper limit determined by an agreed tolerance band in a given balancing group, the TSO will charge a capacity price for the excess capacity. The price charge reflects the procurement costs (monthly capacity price or sliding capacity price). Otherwise, control energy for exceeding or underutilizing of tolerance ranges will be settled by applying the kWh rates x and y.

3.4 COMPARISON OF ELECTRICITY MARKETS IN EUROPE

Now after studying and analysing the different electricity markets in Europe and the methods employed for regulating power, to offset the imbalance between generation and consumption, a brief comparison of these markets is made. Table 3.3 describes the differences in the characteristics of the deregulated markets in the Nordic countries, United Kingdom and Germany. This table is a classification of electricity market regarding the market participants and ownership of the market.

Characteristic	**Nordic Countries**				**United Kingdom**	**Germany**
	Norway	Sweden	Finland	Denmark		
Unbundling	✔	✔	✔	✔	✔	✔
Power pool	✔	✔	✔	✔	✔	✔
IPPs	✔	✔	✔	✔	✔	✔
Third party access-transmission and distribution	✔	✔	✔	✔	✔	✔
Single buyer	×	×	×	×	×	×
Competition in supply	✔	✔	✔	✔	✔	✔
Ownership						
Public	✔	✔	✔		✔	
Private			✔		✔	✔
Municipal				✔	×	
Independent regulation	✔	✔	✔	✔	✔	×

Table 3.3: Comparison of electricity markets in Europe

3.4.1 The Regulating markets

The regulating markets in all of these differ from each other (Table 3.4). In Norway, for each day of the present trading week, individual, one-hour contracts for power are quoted and using the *resultant price/quantity* list, the balance between consumption and production from one minute to the next is achieved. In Sweden Svenska Kraftnät purchases regulating power from

producers who are willing to quickly (within 10 minutes at the outside) increase or decrease their level of production, via weekly and 24-hour contracts.

REGULATION CHARACTERI-STICS	**NORWAY**	**SWEDEN**	**FINLAND**	**UNITED KINGDOM**	**GERMANY**
1. TYPE OF CONTRACTS	HOURLY	HOURLY	HOURLY	HALF-HOURLY	HOURLY
2. BIDS ACCEPTED BEFORE	12 NOON (THE DAY BEFORE DELIVERY)	12.00 (THE DAY BEFORE DELIVERY)	19.00 (THE DAY BEFORE DELIVERY)	BY 19.00	14.30
3. ELECTRCITY PRODUCERS CONSIDERED SUPPLY WITHIN	15 MINUTES	10 MINUTES	10 MINUTES	SHORT TIME HORIZONS	-----
4. REGULATION MARKET HANDLED BY	THE REGULATION EXCHANGE	BALANCE SERVICES	BALANCE PROVIDERS	NATIONAL GRID COMPANY	THROUGHBA LANCING GROUPS (SELF-REGULATION)
5. MINIMUM REGULATION CAPACITY	-----	25 MW	10 MW	50 MW	-----
6. PRICE DETERMIN-ATION METHOD	➢ LOWEST PRICE FIRST (UP-REG) ➢ HIGHEST PRICE FIRST (DOWN-REG) RESULTS IN PRICE/QUANTI TY LIST	STAIRCASE MODEL	➢ CHEAPES T BID FIRST (UP-REG) ➢ MOST EXPENSI VE BID FIRST (DOWN-REG)	-----	BG DIFFEREN-CES PRICING

Table 3.4: Comparison of regulating markets in Europe

At the end of each hour, the regulation price is determined in accordance with the most expensive measure taken during upward regulation (the balance service purchases electricity), or the cheapest measure taken during downward regulation (the balance service sells electricity), used during the hour.

Also in Finland, the ordered regulation shall be capable of being supplied during the entire hour of use in question and all the offered regulations shall be capable of being implemented up to their full capacity within 10 minutes from the order. The minimum capacity of one bid is 10 MW. In Great Britain, Day Ahead and within Day Balancing Mechanism is used to balance power after generators and suppliers (and persons trading over interconnectors)

submit bids and offers to NGC (system operator), to increase or decrease their levels of production or consumption at different points in any half-hour settlement period. Finally, in Germany, the differences between procurement and delivery per period of accounting (15-minute mean power values) within a *balancing group* are compensated by the balancing group manager concerned (BGM).

After the exploration of the already existing regulating markets, the next chapter now focuses on the design of the simulation model based upon the requirements of the model. The object modelling technique for simulating the regulating object model has been utilised for this purpose.

Chapter 4

SIMULATION MODEL FOR THE REGULATING MARKET

4.1 AIM

The simulation model for the regulating power market has to deal with variety of the already existing regulating power markets discussed before. The definitions, rules, operations, timings and pricing mechanisms differ from one market to another. Hence, requirements analysis has to be done to set up explicit requirements for the model, before going any further. These requirements help in finding the solution of the problem while also describing the things in the system and the actions that can be done on these things like the time points, time limits, pricing mechanisms that differ for each of the regulating markets and have to be known correctly for their successful implementation. The participants in the market and their relationship are also defined.

Firstly a Requirements Analysis based on the objects found in the application domain is built to extract essential aspects of the application domain in the regulating market that includes the description of the properties of the objects and their behavior. Then system design (object model, dynamic model and functional model) decisions are made and details are added to the model to describe and optimize the implementation, which is finally implemented using a programming language.

4.2 REQUIREMENTS ANALYSIS

4.2.1 Summary

The goal of the project is to implement a simulation model for balancing power generation and demand in a regulated power market. The model provides the regulating power for the balancing mechanism utilizing the bids submitted by the regulating generators who are willing to offer their services. The simulation model is designed to accept the bids, activates the bids on the basis of regulating power required in close co-ordination with the System Operator (SO). The requirements for this process to be done are discussed here which are regarding critical time points and their definitions, market rules, bid collection, bid selection, pricing models and mechanism. A brief summary of the requirements analysis is explained while the very detailed analysis and description of the requirements are included in Appendix-1.

4.2.2 Structure of the regulating model

In the regulating power market, the main players are the regulating generators ($GENS_{REG}$), the SO, the balance provider who performs the regulating actions for maintaining balances between generation and demand utilizing the simulation module along with those who provide information about demand forecasts, production plans and weather forecasts.

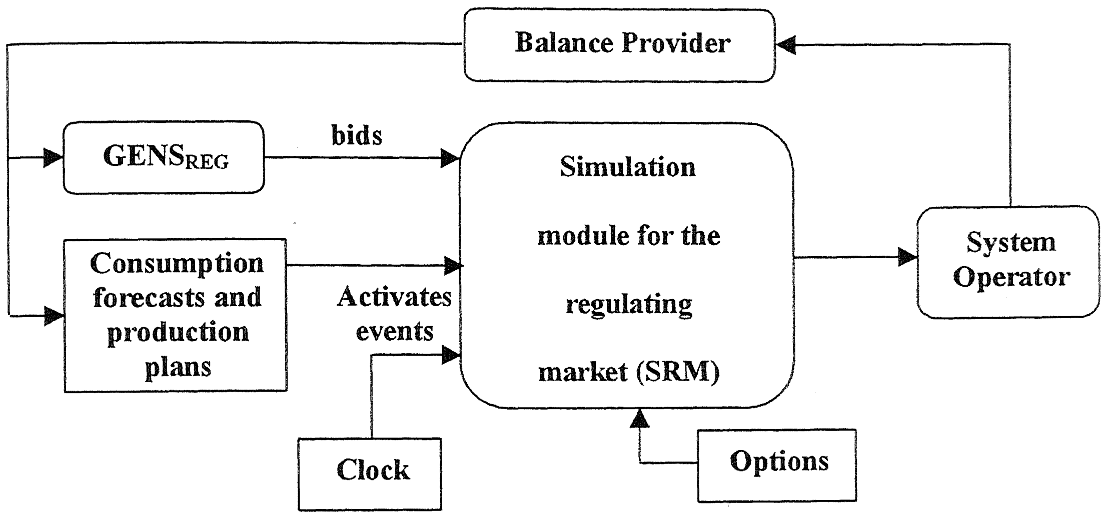


Fig 4.1: The Simulation model for the regulating power market

The main requirements of a power market to provide balancing services is that it should be provided with the bids/offers for regulating power and demand data. Also, knowledge about the market is essential as a simulation model, which can interpret all the regulating power markets is required to be designed. For the implementation of the simulation model, the main analysis is regarding the different market rules in each of the countries. The definitions for the market rules in the Scandinavian countries, Great Britain and Germany that are entirely different have been analyzed.

The information regarding the bids i.e. their time-points and format of submission of these, which are required for the working of the model, has been obtained. The details regarding the critical time-points, the pricing mechanism, the format of bids and the various constraints have been provided in the Appendix-1. The consumption forecasts and the production plans (bids/offers) of $GENS_{REG}$ are generated with reference to the values that are actually persisting in the power markets. This is discussed later in the appendix.

The clock takes care of the events related to the time points for submission of bids and the demand data. The different pricing models of the countries, their bid-selection criteria and the

pricing mechanisms have been analyzed that are required for the simulation module (SRM) to calculate the regulation price and the volume of power from each bid. The Scandinavian countries follow the same time-points and market rules in comparison with Great Britain and Germany, which have entirely different ones. These requirements form the basis for the implementation of the simulation model.

4.3 THE SYSTEM DESIGN

The basic approach to design the simulation model is discussed here. The decisions of how to design the model are highlighted first while the detailed system design is included in the appendix. The overall organization of the simulation model is characterized on the basis of the relative importance of the model's object, dynamic and functional models. This has been first explained. Each model has been divided into its components called subsystems, which encompass aspects of the system that share common property-similar functionality or execution. Here, the modules that are needed for the system are identified (Object model) along with their specifications namely their methods and attributes.

4.3.1 The Object Model

The Figure 4.2 shows an object model of a simulation module for the regulating power market which is required for object oriented modeling and illustrates many object modeling constructs that fit together into the total regulating market model. The class *Simulation Model* defines the operations to activate the selected bids and determine their prices based upon the options of the selected market and the common parameters of the activated bids namely their volume (MW) and price (price/MWh). *Demand Forecaster (DF), Clock, SO,* $GENS_{REG}$, *Simulator for Regulating Market (SRM)* and *Options* are the constituent parts which when aggregated make up the simulation model.

In Fig 4.2, a box having three regions has represented each class. The regions contain from top to bottom: class name, list of attributes, and list of operations. The class *Clock* has got the method of ActivatesEvents, which activates the time-related events of getting the demand and making the RSBs to be provided when the t_{CLK} equals their respective time points. The *DF*, after the clock-activated event of supplying the demand data, provides the SRM with the demand for all the Balancing periods (BP) of the Trading Period using the method setDemand of the following day defined by attribute P_{DF} (demand power to be met).

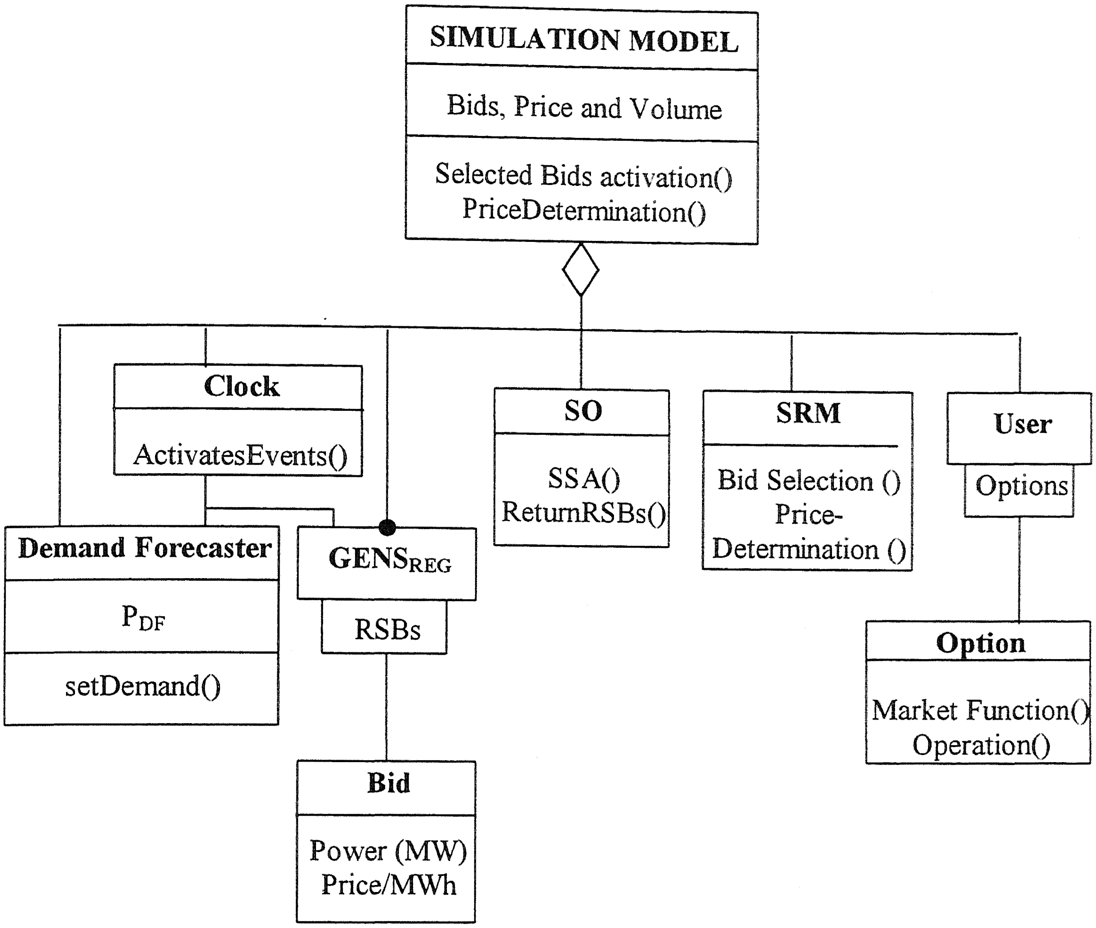


Fig 4.2: The structure of the regulating market

The *Clock* activates the events of demand forecast and bidding. The *GENS$_{REG}$*, after being activated by the system clock at the bidding time submit their *bid* objects to the SRM, each identified by a unique RSB within a given GENS$_{REG}$. Each bid is identified by its volume of Power (MW) and its price (price/MWh). The *SO (System Operator)* does the System Security Analysis (SSA) for the final selection of the selected bids through the methods SSA and ReturnRSBs. These bids are then returned to the SRM for price determination and their activation. The *SRM* does the operations of Bid Selection process by utilizing the algorithm in Requirements Analysis (RA) to choose the bids and the price determination operation after getting the CPM done.

The *User* has to get a list of *Options* objects, each identified by an *Option*, from which the attributes *Market Function* and the *Operation* chooses the pricing models of the different markets.

4.3.1.1 The Object model design

The Object model discussed till now concentrated on the structure of the regulating model. For the implementation process required in coding, slightly different objects were utilized to take care of some important objects like Clock on which the whole working of the simulation model depends upon. This will be discussed now in this section and contains the detailed system design in which a more detailed description of the processing logic and data structures is utilised to sufficiently complete the coding.

From Fig. 4.3, it can be seen that the Simulator is the main player in the object model. The RegulatingMarket, the Spot Market, the SystemOperator, Input Reader and TimeEventSource work in close co-ordination with the Simulator. The Simulator takes care of two important processes-the main method takes care of receiving the information regarding the market and the price model. The output method displays the output of the model on the screen or stores it in an output file.

The RegulatingMarket class is a sub-class of TimeEventListener as it has to be activated when the time event timeEvent occurs. The RegulatingMarket object created takes care of initialising the time related events, the pricing model for the regulating market, the critical time-points, addition of bids and registers the regulating generators to the model, retrieving the total number of regulating generators and calculate the regulating price based upon the above data and obtains the output into a file. A number of regulating generators (GenReg) take part in the regulating market and hence form a separate class. In this class, for every GenReg object added, its bids for the different balancing periods of a trading period are added to the object and a particular bid is also retrieved. The Bid class creates a new Bid object with details regarding the balancing and trading periods, volume of power for up and down regulations and their prices.

The PriceModel class is the basis for the pricing mechanism of the regulating market. Each object of this class calculates the prices and the volume of regulating power for each generator for a particular balancing period of a trading period and provides the Simulator with the results. This class also includes the methods of allocating the volume to the regulating generators on the basis of price they have bid for in the regulating power market. After allocation of the volume, the regulating generators are ordered for providing the regulation power and the results for each GenReg are returned to the Simulator in the output file.

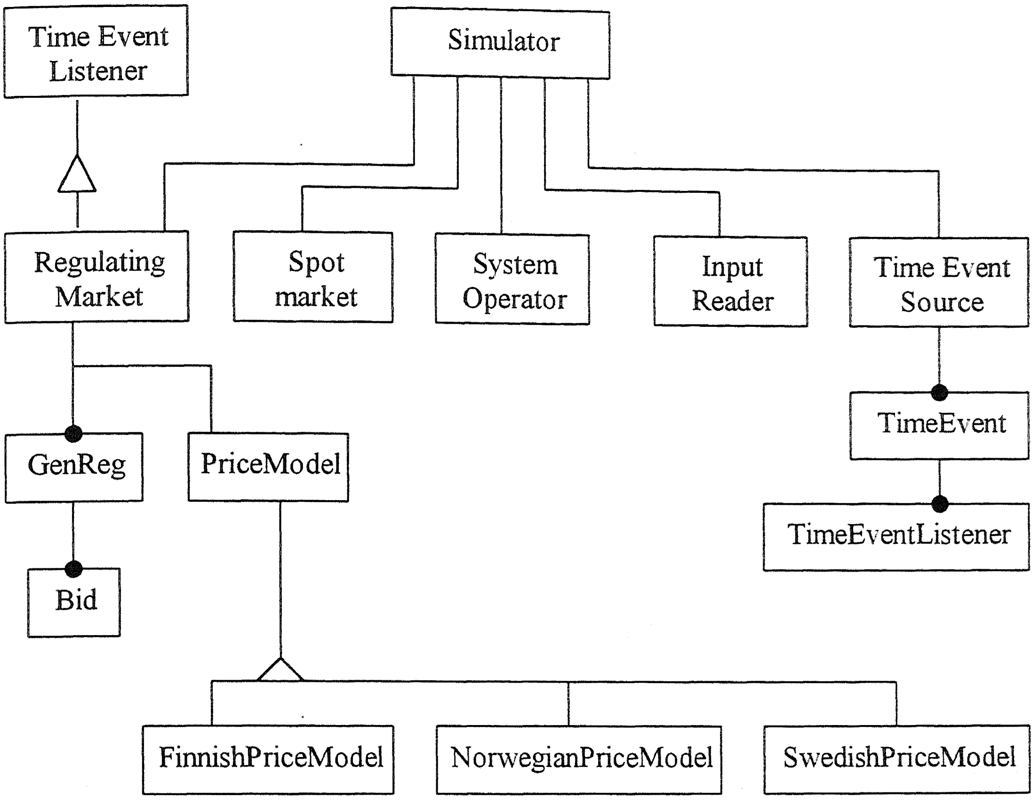


Fig 4.3: Detailed object model of the regulating market

The SpotMarket class corresponds to a very simple spot market in which the spot prices for all the balancing periods of a trading period are initialised and retrieved by the simulating model. This spot price is useful for the calculation of regulation price when the ordered regulation does not take place during real time balancing operation. This type of pricing mechanism is in accordance with that being followed in the Finnish regulating power market.

The SystemOperator class consists of methods that return to the Simulator whether up or down regulation is planned for a particular balancing period of the trading period and the type of regulation that has occurred during real time balancing operation. Upon identifying the type of regulation, the volume of power that is required for up or down regulation is also provided to the Simulator by the SystemOperator object.

An object of the InputReader class reads the input from the input file and feeds the information to the corresponding objects. This class feeds the data of the power bid for and the demand data into the simulating model. It reads the formatted data into the model that has to be utilized in the code for obtaining the regulation prices and power.

The TimeEventSource acts like the clock of the Simulator, which runs all the time independent of other operations. This activates the events that are dependent on the clock like the time to supply demand data, the start of the bidding process and the time to clear the regulation prices. The clock is actually set to a scaled value of the actual time in this model. The TimeEventSource on the basis of the clock and the critical time points for each of the power market adds the timeEvent and the corresponding operation is done after the timeEvent is registered by the TimeEventListener to be implemented. And finally the clock checks all the events to be done and activates them if they are on time.

4.3.2 The Dynamic model

The dynamic model describes a set of concurrent objects, each with its own state and state diagram and change state independently. A single object cannot represent the state of the entire system; it is the product of the states of all the objects in it. Therefore, the state diagram for an assembly, which is a collection of state diagrams, one for each component has been drawn. The aggregate state corresponds to the combined states of all the component diagrams. The aggregate state is one state from the first diagram, and a state from the second diagram and a state from each other diagram. These states also interact among themselves. Hence, the dynamic model of the regulating power market can be assumed to constitute of the state *Simulating Model* as an aggregation of component states: the *DF, Clock,* $GENS_{REG}$, *SO, SRM* and the *User*. Each component also has sub-states and so, the state of the Simulating Model includes the sub-states from each component.

1. Demand Forecaster (DF)

Figure 4.4 shows the dynamic working model of the Demand Forecaster (DF). It is assumed that the DF has got the demand forecast for whole of the trading period. When the system clock, t_{CLK} equals the time for providing demand, t_{DF}; the clock asks the DF to provide the demand data for the following trading day or the forecasted value to the SRM. The DF provides the required data and again returns to its normal 'idle' state.

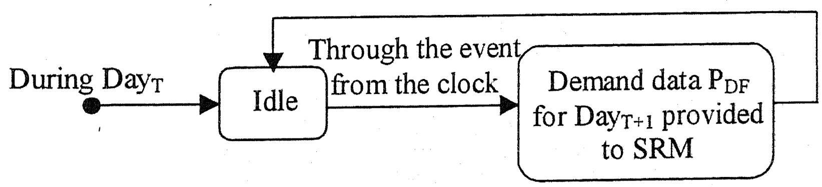


Fig 4.4: State diagram for DF

2. **CLOCK**

The *Clock* is characterised by the system clock, t_{CLK} that runs all the time. When the system clock, t_{CLK} equals the time for providing demand, t_{DF}; the clock asks the DF to provide the demand data or the forecasted value to the SRM and when it equals the time for providing bids, $t_{InitBid}$; the clock asks the $GENS_{REG}$ to provide the bids (RSBs) for Day_{T+1} to the SRM (Fig 4.5).

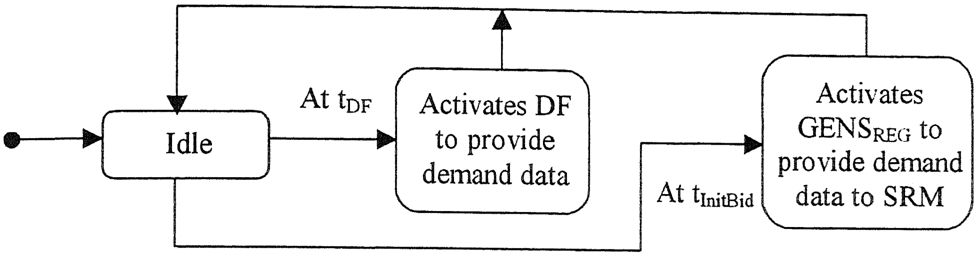


Fig 4.5: State diagram of the Clock

3. **$GENS_{REG}$**

As shown in Fig 4.6, the regulating generators participating in the regulating power market provide the RSBs (bids) for the day Day_{T+1} to the SRM due to the clock activated event when t_{CLK} equals the time for providing the bids, $t_{InitBid}$.

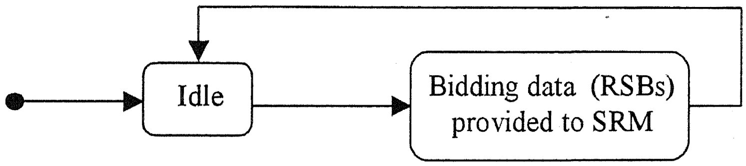


Fig 4.6: State diagram of the $GENS_{REG}$

4. System Operator (SO)

The SO takes care of the operations of selecting the RSBs, which satisfy the system constraints, returning the selected RSBs to the SRM and activating the final RSBs for balancing the power market. The SRM provides the SO with the RSBs for SSA after the collection of the RSBs from the $GENS_{REG}$ at $t_{InitBid}$ has taken place (Fig 4.7).

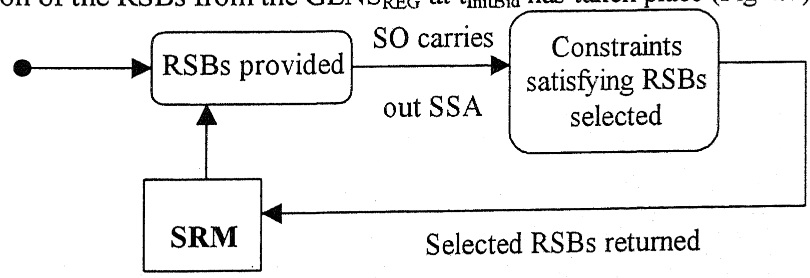


Fig 4.7: State diagram of the SO

5. **SRM**

Figure 4.8 shows the state diagram of the dynamic functioning of SRM. For balancing the power market on Day_T, the SRM collects the RSBs from the $GENS_{REG}$ and runs the algorithm in Requirements Analysis (RA) for selection of bids which are further sent to SO for the SSA analysis to satisfy the system constraints. The SO returns the selected RSBs for the balancing regulation and finally price determination is carried out by the SRM based upon the market chosen by the User. The final RSBs along with their regulating prices are released to the SO which activates the selected regulating generators for balancing the power generation and demand.

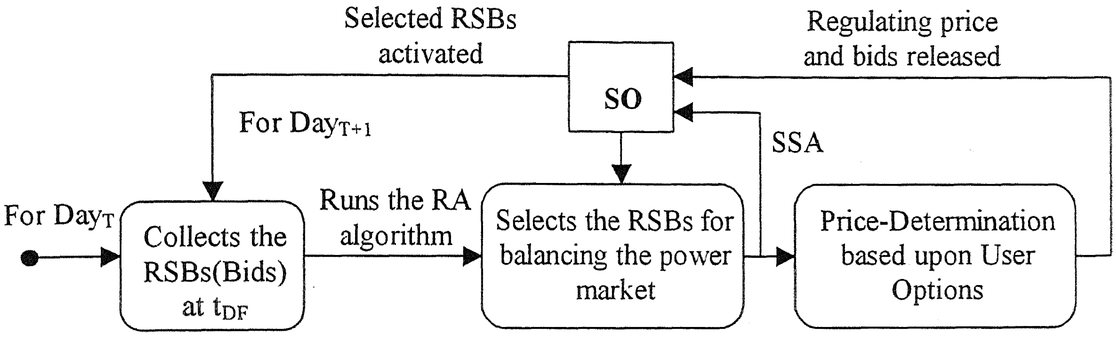


Fig 4.8: State diagram of the SRM

6. **User**

The state diagram of the User (Fig 4.9) starts with the state of selecting the type of operation and then the type of Market Function through the class of Options that has been provided to it. After selecting the Options provided to it, these are returned to the SRM for the operation of price determination.

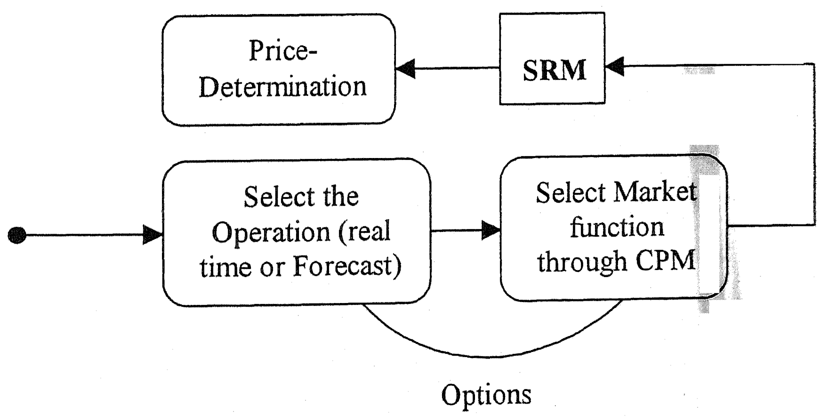


Fig 4.9: State diagram of the User

4.3.2.1 The dynamic model design

The detailed design of the dynamic model is explained below that has been utilised in the implementation process of the Simulation model for a regulating power market. The TimeEventSource class, which is the clock of the Simulator, activates the time-related events i.e. the dynamic events of the simulating model. This clock runs all the time independent of other operations which checks the events of time to provide demand data and bids, time to regulate power and the time to clear prices if the time-points of the events are on time. The TimeEventSource object adds the event on the basis of its time-point and registers that event to the TimeEventListener object, which activates the particular event on its time.

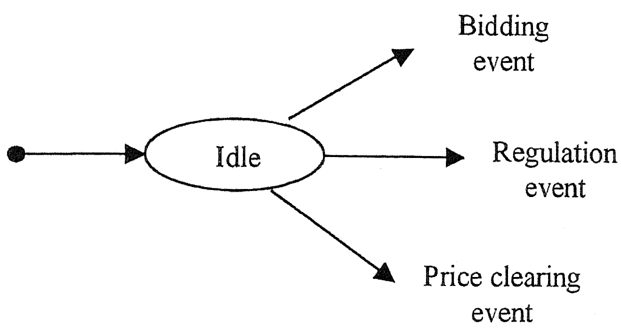
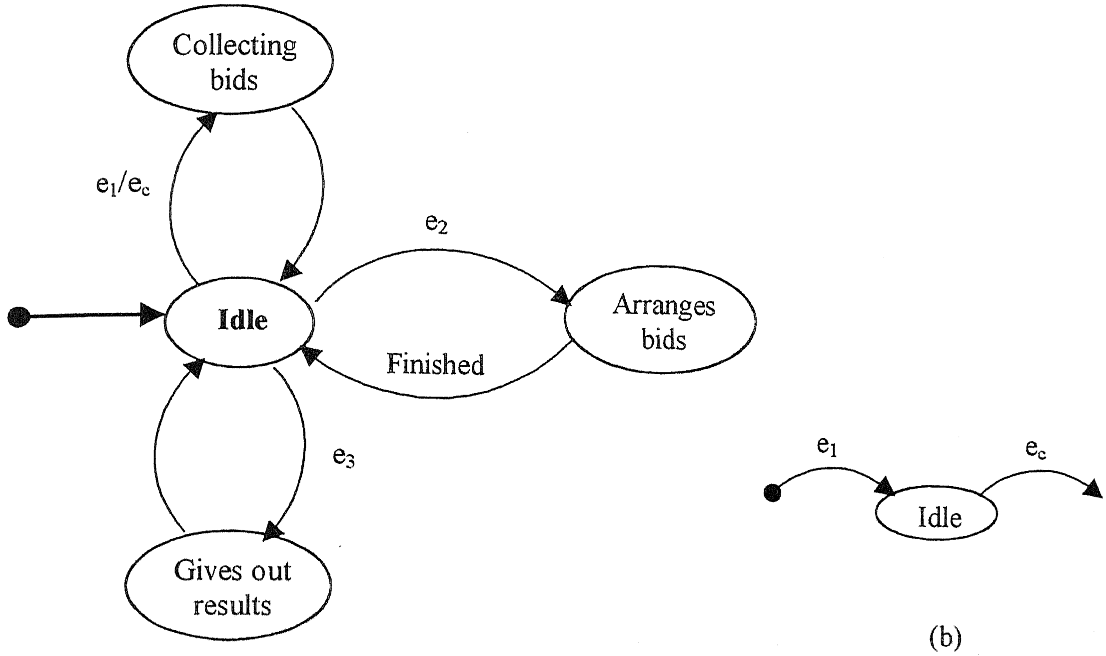


Fig. 4.10: Time events in the dynamic model

For the time event to provide bids to the Simulator, a TimeEventListener is registered for the TimeEvent, which activates the RegulatingMarket. The TimeEventSource object does this process of registration and thus the bidding process gets started where the Simulator collects all the bids from the regulating generators. The RegulatingMarket on the basis of PriceModel chosen calculates and allocates the regulating volume of power to the generators taking into consideration the prices that the regulating generators had bid for.

In the Fig. 4.11 (a), the events that happen in the RegulatingMarket are shown. Till the event of getting the bids, the RegulatingMarket is in idle state. Then through the activation event of collecting bids (e_1) from the clock, the collection of bids from the regulating generators is done (e_c). This process of collecting bids is depicted in a more detailed manner in Fig. 4.11(b) of the events e_1 and e_c that take place. When the TimeEvent of regulating power for a balancing period is approached, the Simulator starts acting and balances the power generation and demand through its RegulatingMarket. The results of the selected regulating generators and the regulation price are given out after the activation of the event e_3.



(a) (b)

Fig. 4.11: The regulating market events

4.3.3 The Functional Model

The simulation model for regulating market is responsible for the selection of the system constraints satisfying bids and calculation of regulation price. Figure 4.12 shows the data flow diagram for the simulated regulating market. The input vectors are due to the Clock that activates the clock-related events, $GENS_{REG}$, DF and the User. The internal data stores are of the RSBs and the Demand data.

The processes in the diagram can be divided into three sub-processes: collecting the required RSBs and demand data, selection of the RSBs for balancing the power market and calculation of the regulating price using the different options. The collecting processes are the RSBs and demand collection by SRM due to clock initiated events. The clock sends the activation signal to the $GENS_{REG}$ and DF to provide the bid and demand data to the SRM at their respective time-points. In the selection processes, the algorithm from requirements analysis is used to the most economic RSBs and then SSA by SO is done to select the final RSBs, which are to be utilised for the balancing power market.

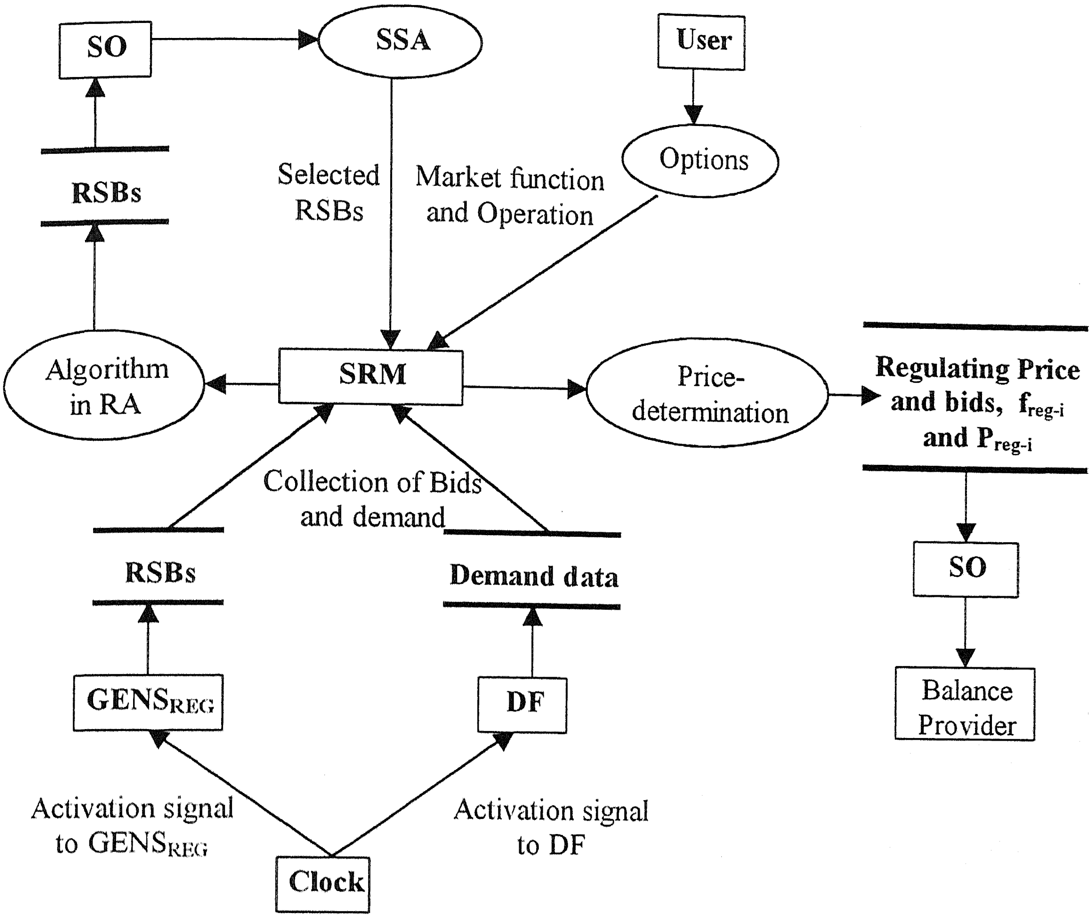


Fig 4.12: Functional model of the regulating market

In the calculation processes, the User provides the information regarding the market and whether it is for real-time or forecasting operation to the SRM. Based on this, the Price determination process for the regulating power is initiated to calculate the regulating power price. The model does not specify when, why, and how the values are computed but specifies the meaning of operations and constraints and how output values i.e. regulating price and bids in the computation are derived from the input values of the RSBs, demand data and market options. The RSBs and their regulating prices are then sent to SO for their activation to balance the power market and to determine the prices regarding the settlement.

The functional model shows the computational and the functional derivation of the data values. Figure 4.13 depicts the flow of parameters and the processes that are done. The GenReg during the timeEvent of providing the bids activated by the TimeEventSource provides the bids to the Simulator for both up and down-regulation while the SO provides the demand data for each balancing period of the trading period. When the timeEvent for

regulation is activated, the Simulator carries out the price determination process. Simultaneously, the PriceModel selects the pricing mechanism and provide it to the Simulator for the price determination process and gives out the Regulation price and volume of power that has to be provided by each GenReg.

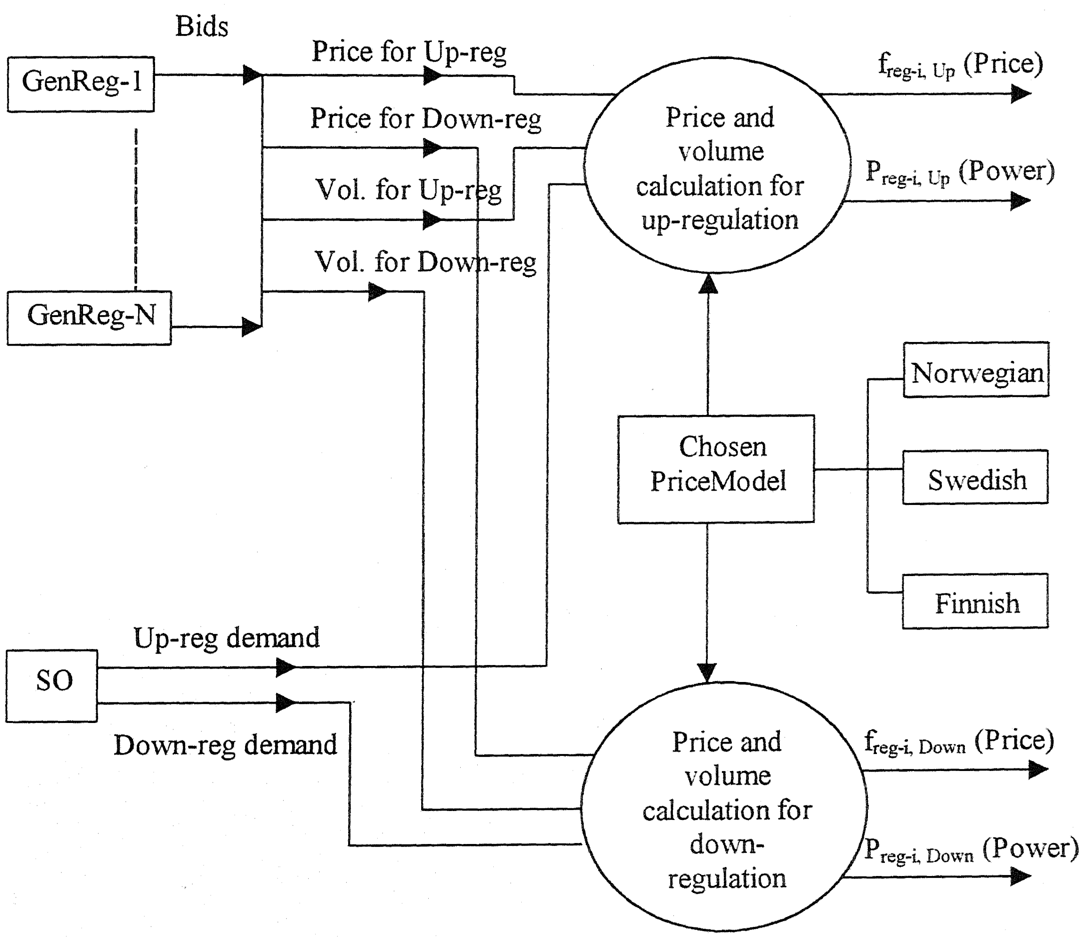


Fig 4.13: Detailed functional model

4.4 TESTING

The testing for the model could not be done for real time data because actual bid data of the power market are confidential under all circumstances and were not available. Therefore, the model was tested for some generated data based upon the final volume and prices of regulating power released in the Nordpool website. The model was successfully tested for the data and identified the various regulation prices in each of the regulating markets that followed different price mechanisms.

Based upon the object-oriented modeling of the regulating power markets, the simulation module was designed and programmed using Java language. The pricing mechanisms of Great Britain and Germany are not made public rather only the mechanism of functioning of their regulating markets are made known. The reason for this may be to keep them confidential due to their big markets in also the regulation of power for balancing purposes. So, the model was tested only for the Scandinavian countries of Norway, Sweden and Finland, which more or less follow the same rules and time-points.

Since the bid data are confidential for all of the regulating power markets, the data for bids and demand were made by going in the backward direction of knowing first the final regulation price and volume of power traded for each balancing period of a trading day in each of the regulating markets. This data was obtained from the NordPool website where the final regulation price and volume traded for all of the balancing periods of last few days are published. Then, the bid data and the demand data were generated assuming some random number of generators that are taking part in the regulating power market. This was done by calculating the average volume of power to be supplied from each generator and assigning the bid data accordingly i.e. for the volume of power to be traded, some value nearer to the average value within a range is taken. The same has been followed for the regulation price too. The bid data was generated using this principle.

The demand data for the total volume of power to be traded during whole of a particular balancing period was also similarly created. This generated bid data and demand data from the real time data was later used to test the simulation model. The model was programmed to first accept the input data in the format of number of generators bidding for the balancing period, their bid data for both up and down regulation, the total demand to be met and the number of trading periods. This was done separately for all the three regulating power markets of

Norway, Sweden and Finland. Then the program was run after selecting the regulating market that the model has to simulate.

The simulation module has been tested for a simple data set consisting of bid data from two generators participating in the regulating market. These generators bid for three Balancing Periods (BP) of one Trading Period (TP). Although the generators bid both for up and down regulation simultaneously and the simulation model was tested for both, the results shown below are only for the case of up-regulation. The Figure 4.14 illustrates the regulating power required for three of the BPs of the one TP considered. The SO provides this data to the SRM.

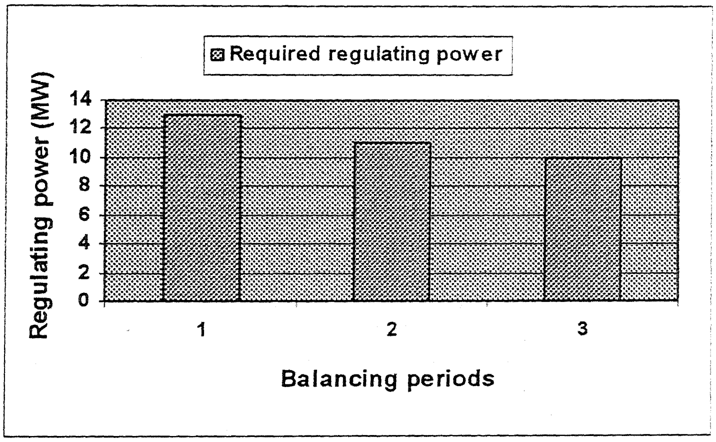


Fig 4.14: Regulating power required during three balancing periods

The figures 4.15 and 4.16 depict the bid data of generators Gen1 and Gen2 in the format of price ($/MWh) and volume (MW) required for the three BPs of the TP.

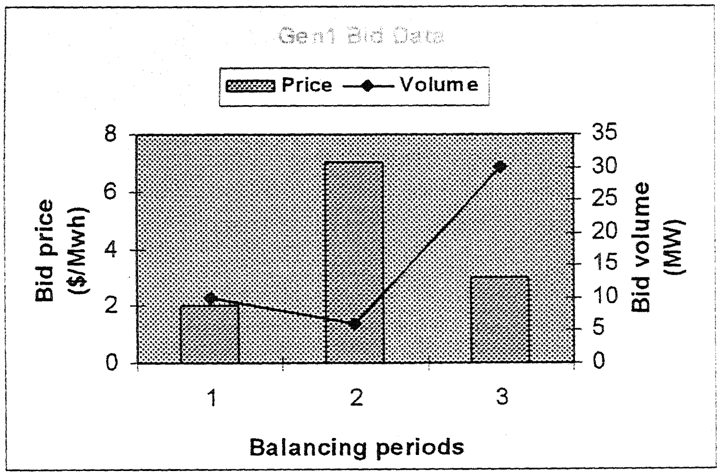


Fig 4.15: Bidding data of Gen1

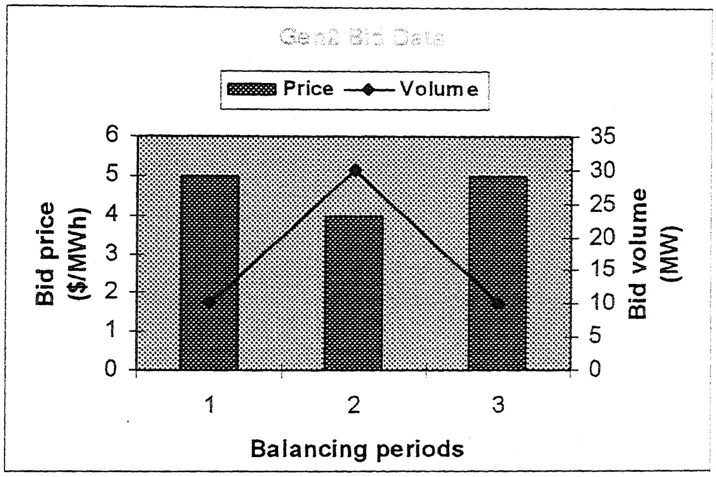


Fig 4.16: Bidding data of Gen2

The SRM after accepting the bid data from the regulating generators was run for different regulating markets. The allocation of volume of power to each of the generators was based upon the same criteria of allotting the contract to the lowest bid first. Hence, the allocation of regulating power is same for all the regulating markets and is given below in Fig 4.17. In this figure, volume based upon minimal regulating price offered by the generators was allocated by the SRM, which in turn are activated by the SO for regulation.

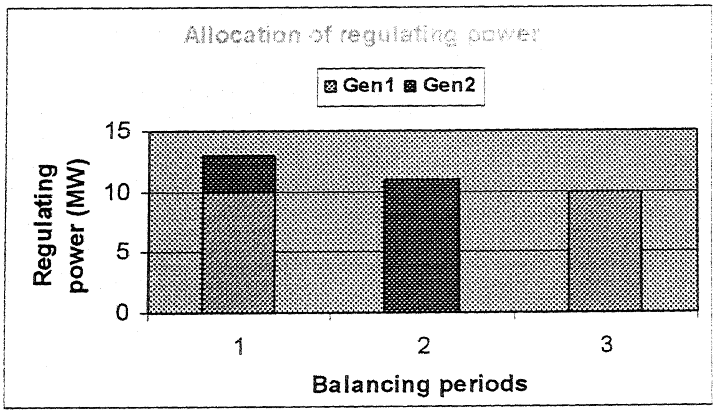


Fig 4.17: Allocation of regulating power to Gen1 and Gen2

The output of the SRM simulating each of the regulating market varies in the calculation of regulating price. In Norway, the price of the regulating power is the same price the regulating generators had bid for, if they were selected for the particular delivery hour (Price/Quantity list). This is illustrated in the Fig 4.18.

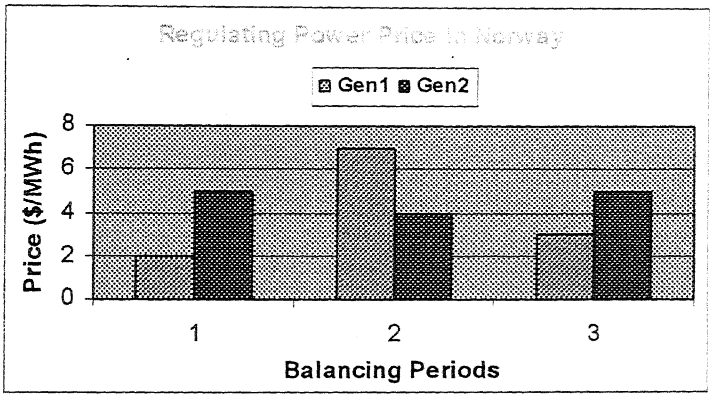


Fig 4.18: Regulation price in Norwegian market

In the case of Swedish regulating market, the up-regulation price offered to all the regulating generators is the most expensive measure, while the down-regulation price is the cheapest measure used during the BP (Staircase model). Hence, the regulating price offered to each of the generators is same for each BP under consideration. This can be noticed from Fig 4.19.

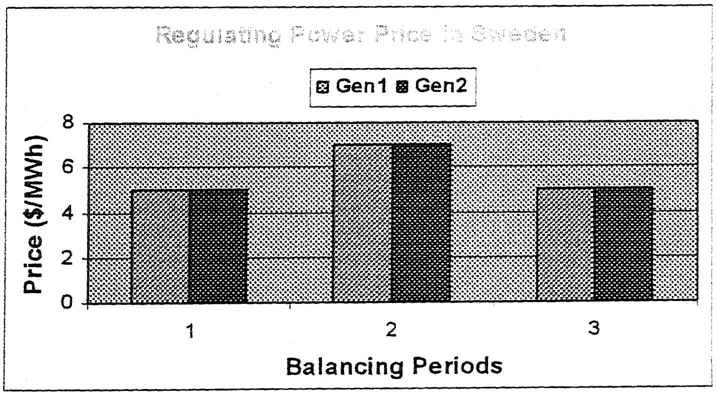


Fig 4.19: Regulation price in Swedish market

In Finland, the up-regulation price offered to all the regulating generators is the most expensive measure, while the down-regulation price is the cheapest measure used during the hour (fig 4.20). If no up-regulation has been made or if the hour has been defined as a down-regulation hour and vice versa, then the price for price area of spot market (Elspot FIN) is used as the sale price or purchase price of balance power. For the first and third BPs, up-regulation has not taken place that was actually ordered for. Hence, the spot price has been paid for the concerned BPs.

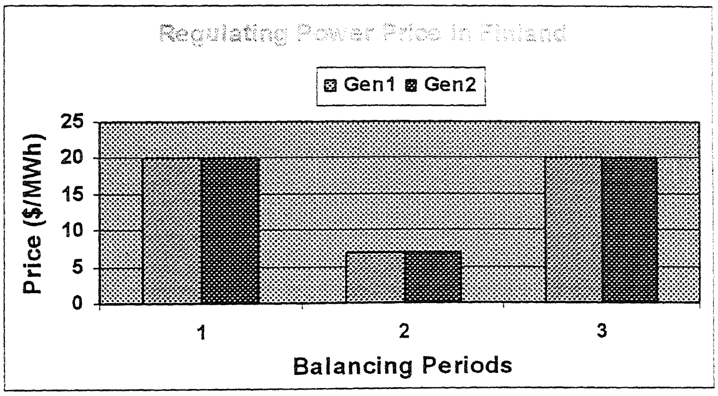


Fig 4.20: Regulation price in Finnish market

The data tested shown is of three BPs, one TP and of two generators participating in the regulating market to explain the functioning of the simulation module. However, this module has also been tested for 24 BPs, one TP and of four regulating generators whose data is more closer to the real-time data obtained from the website of NordPool for testing purposes. The module thus simulates the different regulating markets successfully. These are inferred from the different regulation prices obtained from SRM was simulated the markets, the time rules and time points, which are different for each of the regulating markets of Norway, Sweden and Finland.

Chapter 5

CONCLUSIONS

Electric utilities throughout the world are confronted with deregulation of the electric power systems. The old school of thought that considered electric utility power generation, transmission, and distribution a "natural monopoly" has given way to a new school of thought of vertically unbundled market. Today, there is a widespread view among legislators, regulators, industry analysts, and economists that the generation segments of power supply in today's environment would be more efficient and economical in a competitive market. Major segments of the electricity industry are being restructured. The industry has currently been transformed to an entity involving competitive market where retail customers can choose the suppliers of their electricity.

In a competitive electricity market, the supply of regulating power is separated from the actual tasks of the net operator and special markets are set up for these purposes which are similar to the spot markets but with different time limits and different number of power providers. In this thesis work, a generic model is proposed that brings the relationship between the regulating market, the net operator, the regulating generators and the other participants of a regulating market. For this, the different existing markets in Europe are analysed and compared to create a basis for the design and implementation of the simulation module for the regulating market. The different electricity markets of Europe, which have been analysed are that of the Scandinavian countries, the UK and of Germany along with their regulating markets.

All the countries maintain their own markets for regulation. The regulating markets in the Scandinavian countries follow more or less the same regulating principles, as they constitute in the Nordel power system. The volume of regulating power traded in each of these depends on the size of the power system i.e. on the total generation capacity. The UK regulating market is based on the principles of New Electricity Trading Arrangements (NETA) and is the biggest market of regulating power. Germany has no regulating market as such but the Balancing groups (BG) take care to maintain balance within their control area. Excluding the regulating market of Finland, in all other regulating markets the price of the regulating power

is found before the hour of use. A comparison of the differences between the regulating markets (balancing market) in all of the countries mentioned above has been made.

The design of the simulation model has been carried out on the basis of the object-oriented modelling that has been presented in this work. The model is then coded for implementation and tested for generated values of bid and demand data. The testing for the model for real time data is out of scope of this work because bid data from the regulating generators are kept confidential under all circumstances.

The simulation model presented here forms an ideal basis for calculating the regulating price and allocating volume of power to the generators participating in the regulating market. The market is modelled as a connection of various players in the regulating power market, where each player corresponds to the participants of it. The main objective of making a simulation model for the regulating power markets has been achieved. This model helps in simulating the various already existing regulating markets of Europe.

During the course of the research work carried out in this thesis, the following few areas of further research have been identified.

- In the present work, the testing of the simulation model could not be done for real time data because actual bid data of the power market are confidential under all circumstances. Therefore, the model has to be tested for real bid data to check the proper functioning of the model.
- Although the regulating markets of United Kingdom and Germany were studied and analyzed, these markets were not implemented in the module because of the non-availability of their pricing mechanisms. The pricing mechanisms have to be studied and implemented in the module.

APPENDIX

APPENDIX-1

1.1 REQUIREMENTS ANALYSIS FOR REGULATING MODEL DESIGN

1.1.1 Introduction

- **Purpose:** To design a model that brings relationship among all participants of a regulating market - for handling of regulating power.
- **Scope:** A simulation module for a regulating market.

1.1.2 Overview

The main players in this model are the regulating generators, the System Operator, the balance provider who perform the regulating actions for maintaining balances between generation and demand utilising the simulation module along with those who provide information about demand forecasts, production plans and weather forecasts. The module works with reference to a clock, which identifies the different functions that the module has to perform at particular time points such as acceptance of the bids, the pricing model to be utilised. Therefore, it is required to know the different time points and their periods to correctly ascertain the functioning of the model.

1.1.3 Definitions

1. **Regulating power:** As a result of a regulation request made by the System Operator (SO), the electric energy relating to the power delivery between SO and the balance provider.
2. **Regulating Supply Bids (RSBs):** A Regulating Supply bid is a proposal from the participating regulating generators to SO for reducing generation or to increase consumption.
3. **Regulating Supply Offers (RSOs):** An offer is a proposal from the consumers to SO or increasing generation or to reduce consumption.
4. **Reserve capacity:** System capacity for supplying reserve power due to planned or unplanned power plant outages.
5. **Down-regulation:** Reduction in generation or increase in consumption.
6. **Up-regulation:** Increase in generation or reduction in consumption.

7 **Minimum Bid size ($P_{B\ min}$):** The minimum capacity of regulating power that the regulating generators must be able to provide.

8 **Balancing Period (T_{BP}):** To take care of imbalances, each trading day of period T_{TP} is divided into equal balancing periods for which the regulating generators bid for to take part in the balancing mechanism.

9 **t_{reg}:** The time for which the planned regulations are to be provided before and after the balancing period.

10 **$T_{Bid\ lim}$:** The period before which the bids are allowed to change before the beginning of the particular hour of use.

11 **P_{Rmin}:** The minimum regulating power required for balancing generation and consumption in a particular balancing period.

1.1.3.1 Periods on trading day

The trading at the regulating market is always done for a particular period, called "*trading period*", which has the duration T_{TP}. T_{TP} is always 24 hours and it starts at particular time point $t_{TP,\ limit}$ each day and ends at $t_{TP,\ limit}$ the next day (Fig. 1). For a particular T_{TP}, where it started is called the Trading Day (Day_T). The day before is called Day_{T-1} and the day after Day_{T+1}. Some particular time-point t_x at day Day_s, where $s \in \{T, T-1, T+1\}$, is referred to as $t_{x,\ s}$.

T_{TP} is divided into n *balancing periods*. Each balancing period has the duration T_{BP}, where $T_{BP} = T_{TP} / n$. The i-th balancing period starts at time point $t_{BP,\ i,\ start} = t_{TP,\ limit} + (i-1)*T_{BP}$ and ends at the time point $t_{BP,\ i,\ ends} = t_{TP,\ limit} + i * T_{BP}$.

1.1.3.2 Critical time points on the day before trading

t_{DF} is the time point on Day_{T-1}, where the generators get a demand forecast for the trading period which starts on Day_T (Fig A-1). The SO gives this forecast.

$t_{B,\ init}$ is the time point when generators should bid for all the balancing periods in the trading period, which starts on Day_T.

The generators can change their bids for a particular balancing period i.e. on Day_T from $t_{B,\ init}$ until $t_{B,\ final,\ i}$ (the i-th bidding period), where

$t_{B,\ final,\ i}$	=	$t_{BP,\ i,\ start} - T_{Bid\ lim}$ on Day_T	if	$(t_{BP,\ i,\ start} - T_{Bid\ lim}) > 0$
	=	$24 + (t_{BP,\ i,\ start} - T_{Bid\ lim})$ on Day_{T+1}	else	

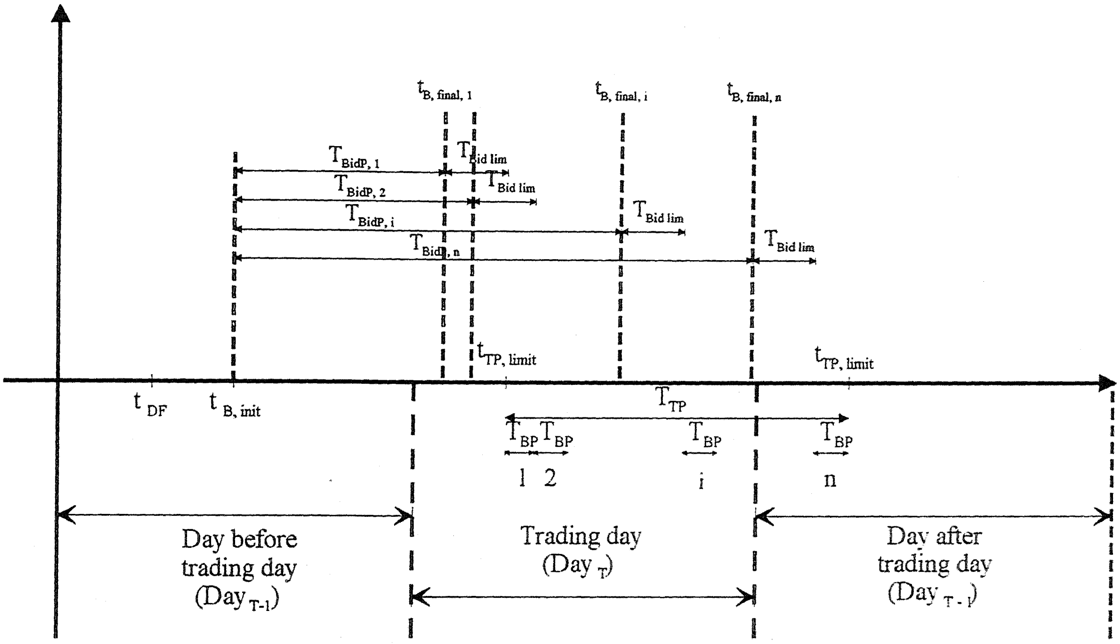


Fig A-1: The critical time points for trading at a regulating power market

The time length of the i-th bidding period is called $T_{BidP,\ i}$. At the time point t_{TSM} (point for submission of total system margin), the generators get information from the SO concerning the difference between the forecasted consumption of the regulating power and the already offered supply (bids) of the generators (only for British regulating market).

1.1.3.4 Special time points for Great Britain

t, Normal time variables → exact time points

T, capital time variables → denote a particular time period

1 t_{DF} : time point when the demand forecast for the following day is published.

2 T_{TP} : total time period for trading on a particular day, trading period.

3 $t_{B,\ init}$: time point for submission of the bids for the following day.

4 t_{TSM} : time point for submission of total system margin.

5 t_{NRSM} : time point for submission of national and regional system margin.

1.1.4 Pricing models

The pricing models utilised in the regulating markets of Norway, Sweden and Finland are similar except for the way in which the final price of the regulating power is determined. To have a more clear understanding of it, we will now have a brief look into the pricing models of these countries. The general way of classification of the bids which is common to all these

markets is then mentioned through a bid selection algorithm although Germany has an entirely different one followed by the different final pricing mechanisms.

1.1.4.1 Norway

1 The bids for the regulating market (RSBs) are obtained from producers and consumers in which market players quote a price and quantity for upward and downward adjustment.

2 For the regulating market, the bids from producers and consumers are obtained in which market players quote a price and quantity for upward and downward adjustment.

1.1.4.2 Sweden

1 RSBs for balance regulation are arranged in order of price and form a "staircase" for each hour of operation.

2 Regulation price is determined in accordance with the most expensive measure taken during upward regulation (the balance service purchases electricity), or the cheapest measure taken during downward regulation (the balance service sells electricity), used during the hour. This final regulation price applies to all those selected to regulate the balance upwards or downwards.

1.1.4.3 Finland

1 The highest price of up-regulation used during the hour will be the price of balance power obtained by Balance provider from Fingrid System Oy (sale price of balance power). If no up-regulation has been made or if the hour has been defined as a down-regulation hour, the price for price area Finland in Nord Pool (Elspot FIN) is used as the sale price of balance power.

2 On the other hand, the lowest price of down-regulation used during the hour will be the price of balance power fed to Fingrid System Oy by Balance provider (purchase price of balance power). If no down-regulation has been made or if the hour has been defined as an up-regulation hour, the price for price area Finland in Nord Pool (Elspot FIN) is used as the purchase price of balance power.

1.1.44 Germany

1 Within the tolerance band, in the high tariff zone, up to 6 full-load hours (relative to the reference value of the tolerance band) may be transferred to the following settlement period. For the low tariff zone, 4 full-load hours may be transferred to the following settlement period. Account imbalances over and above that level are charged

or paid for by the TSO at asymmetrical market prices (per kWh). Deficits will be charged for at x and surpluses will be credited for at y.

2 Outside the tolerance band: In the event of consumption over and above the upper limit determined by an agreed tolerance band in a given balancing group, the TSO will charge a capacity price for the excess capacity. The price charge reflects the procurement costs (monthly capacity price or sliding capacity price). Otherwise, control energy for exceeding or under utilising of tolerance ranges will be settled by applying the kWh rates x and y.

1.1.5 Bid Selection Algorithm

Step 1: Bids are accepted in the format P_i (MW), f_i (price/MWh) for each balancing period, T_{BP}.

Step 2: If regulation is down go to Step 5 else continue.

Step 3: Up regulation bids are P_i, f_i where i = 1,..........N, where N→ no. of bids for the balancing period starting from $t_{BP, i, start}$ and ending at $t_{BP, i, end}$ of the trading day Day_T.

Step 4: Bids are arranged for lowest price for up-regulation.

If $f[i] \geq f[i+1]$, go to Step 6

Step 5: Bids are arranged for highest price for down-regulation.

If $f[i] \leq f[i+1]$, go to Step 6

Step 6: Constant, $c = f[i]$, $f[i+1] = f[i]$, $f[i+1] = c$. This is repeated for all the bids until $i = N$ i.e. all the RSBs that the regulating generators had bidded.

Step 7: Thus, all the bids are arranged and final f[1], f[2], ...f[N] are obtained.

Step 8: For the total regulating power, P_{Rmin} required for each balancing period (T_{BP}), only those bids are selected such that $f[1] + f[2] + \ldots\ldots f[j] \geq P_{Rmin}$ where 'j' varies from i to N.

- **Norway:** After the RSBs are arranged according to the bid selection algorithm, the price of the regulating power is the same price the regulating generators had bid for if they were selected for the particular delivery hour (Price/Quantity list).
- **Sweden:** The bid selection algorithm is utilised first to obtain the final RSBs. The RSBs that are selected are arranged in the order of their price for both up and down regulations and thus forms a 'staircase'. The up-regulation price offered to all the regulating generators is the most expensive measure, f[N] while the down-regulation price is the cheapest measure used during the hour (Staircase model).

- **Finland:** Finland also utilise the same bid selection algorithm to get the final RSBs. The up-regulation price offered to all the regulating generators is the most expensive measure, f[N] while the down-regulation price is the cheapest measure used during the hour. If no up-regulation has been made or if the hour has been defined as a down-regulation hour and vice versa, then the price for price area of spot market (Elspot FIN) is used as the sale price or purchase price of balance power (Price/Quantity list).

1.1.6 Germany

In Germany, a special type of pricing mechanism based on tolerance band is in use. So, to describe the pricing mechanism and to make a an algorithm for it, some special definitions are defined which are applicable only to it.

1.1.6.1 Special definitions

1 Tolerance band: The standard tolerance band is +/- 5% of the reference value. The reference value is defined as the value of the cumulative simultaneous peak loads at all the extraction points in a balancing group within a control area, within the measured balancing periods, measured over the course of trading.

2 P_{TBImb}: The tolerance band power imbalances for each balancing period of a Balancing Group (BG)is given by P_{TBImb}.

3 P_{TImb}: The total imbalances for each balancing period during real time feed-in and extraction.

4 H_{TZ}: The energy deviation value for high tariff zone (6 full load hours).

5 L_{TZ}: The energy deviation value for low tariff zone (4 full load hours).

1.1.6.2 Pricing mechanism

1 The pricing in Germany is based on the tolerance band. Deviations exceeding these tolerance limits are charged for additionally. The tolerance band imbalances for each 15 minute period is given by P_{TBImb}.

2 The Balancing Group (BG) provides the total imbalances, P_{TImb} for each 15 minute balancing period. The energy deviation value for high tariff zone is H_{TZ} and for low tariff zone is L_{TZ}.

3 If $P_{TImb} > P_{TBImb}$ and $(P_{TImb} - P_{TBImb}) > H_{TZ}$, then P_{TBImb} is debited or credited on the basis of it being positive or negative into the high tariff account and the excess $(P_{TImb} - P_{TBImb})$ will be charged for separately at an energy and capacity price or reimbursed at an agreed energy price of x price/kWh.

4 If $P_{TImb} > P_{TBImb}$ and $(P_{TImb} - P_{TBImb}) > L_{TZ}$, then P_{TBImb} is debited or credited on the basis of it being positive or negative into the low tariff account and the excess $(P_{TImb} - P_{TBImb})$ will be charged for separately at an energy and capacity price or reimbursed at an agreed energy price of y price/kWh.

5 If $P_{TImb} < P_{TBImb}$, then they are accounted for by control energy for deviations occurring within these limits.

6 Through continuous addition of the feed-in/extraction imbalance within the tolerance band for a particular BG, the final high and low tariff accounts for that particular closing of settlement period are obtained. The final pricing is done as given in 3, 4 and 5.

7 In the event of consumption over and above the upper limit determined by an agreed tolerance band in a given balancing group, the TSO will charge a capacity price for the excess capacity as discussed in 3 and 4.

1.1.7 General

1.1.7.1 Module's job

1 To maintain the balance between generation and consumption of power in a power market utilising the regulating power.

2 Find out the price and volume forecast.

3 Give output as which generators are to be activated and the volume of power that the generator will be providing for regulating power.

1.1.7.2 Functions of the module

1 To accept regulating supply bids (RSBs) from generators and.

2 Production plans and demand forecasts are to be accepted.

3 Make an estimation of the regulating power required in each balancing period of the following day.

4 Determine the price of regulating power using the chosen pricing model utilising the function CPM which is discussed later.

5 Activate the bids of generators or inform the generators (only those which satisfy economical and technical conditions).

1.1.7.3 User characteristics

1 Provide the demand or load required in Balancing Period (BP).

2 To make sure that the bidding process takes place and RSBs are submitted.

3 The SO who also is a user and who has got to maintain system balance with respect to power has to carry out system security analysis.

1.1.7.4 Assumptions and dependencies

1 The regulation providers provide the required amount of power as per schedule.

2 The SO or the balance provider has sufficient reserve capacity in case of disturbances.

3 If some bids are not satisfying the system constraints and if lead to any contingency or congestion problems, they are excluded and the total sum of power of remaining bids are calculated. If the sum is less than the required regulating power, then the bids excluded are again revised to reduce the number of removed constrained bids. The system margin for each hour is to be calculated.

1.1.8 Specific market rules

The regulating power markets in the analysed markets of Europe have different time limits and different limits for constraints regarding the bid selection and their size. These are mentioned in the table (Table A-1) below. All time points are not in use in all of the regulating markets and they are represented by *. These limits are strictly followed for the adjustment of imbalances between generation and demand of power.

Country/ Time rules	t_{DF}	$t_{B,\,init}$	T_{BP}	$P_{B\,min}$	$T_{Bid\,lim}$	T_{Impl}	t_{reg}
NORWAY	*	12.00	Hourly	*	*	15 min	*
SWEDEN	*	12.00	Hourly	25 MW	30 min	10 min	10 min
FINLAND	*	19.00	Hourly	10 MW	10 min	10 min	15 min
GREAT BRITAIN	9.00	11.00	Half-Hourly	50 MW	3-1/2 hours	Short time horizons	*
GERMANY	*	14.30	Hourly	*	*	*	*

* → not utilised in the countries

Table A-1: Specific market rules in each of the countries

APPENDIX-2

1.2 DETAILED SOFTWARE DESIGN

In the detailed software design of the simulation model for the regulating market, all the classes that make up the model are discussed. Then the methods that take care of the different processes and operations are also discussed along with the attributes and other parameters that are utilised in each of the methods. Here, the top-down strategy of the complete simulation model is utilised. The main classes that have lead to formulation of the coding have been discussed here. The classes for pricing models of Norway, Sweden and Finland follow the same mechanism discussed before.

1 The Simulator class corresponds to a simulation environment for the regulating power market. The simulator creates an object Simulator that includes all the details of the scale for clock, the price models to be chosen, the time-points of bids and demand data and the time points of balancing and trading periods. The other classes of RegulatingMarket, SystemOperator, SpotMarket, InputReader and SpotMarket are similarly explained later in this section. In its main routine, the main processes and operations that are to be undertaken are taken care of using the arguments for each of them.

Simulator
+simulator:Simulator -regulatingMarket:RegulatingMarket -timeEventSource:TimeEventSource -inputReader:InputReader +spotMarket:SpotMarket +systemOperator:SystemOperator
+main:void +Simulator +output:void

Table A-2: The Simulator class diagram

The values of the various attributes are then assigned to each of them to catch any exceptions. It has also got a method to display the output results onto the screen or to store them in an output file. These methods and attributes are shown in Table A-2.

2 The RegulatingMarket class is a sub-class of the TimeEventListener. The RegulatingMarket creates objects that include details regarding PriceModel, the bid data, the start and ends of a balancing period, the number of balancing and trading periods. The attributes lTimeBetweenTradingPeriods, iIdStartToBidEvent, iIdTBPStartEvent, and iIdPriceKnownEvent represent the time in minute between the trading periods, the event number to start the bid process, the event number for the balancing period (BP) to start and the event to release the regulation price respectively.

TimeEventListene **RegulatingMarket**
-lTimeBetweenTradingPeriods:lon -iIdStartToBidEvent:int -iIdTBPStartEvent:int -iIdPriceKnownEvent:in -vGenReg:Vecto -priceModel:PriceModel
+RegulatingMarket +addGenReg:void +initEvents:voi +actionPerformed:voi +addGenBid:voi -timeToBid:void +calcDirty:void -finalOutput:voi
myGenReg:Vecto

Table A-3: The RegulatingMarket class diagram

This class starts calculating regulating price and power on the basis of classification of the price model chosen. The methods specified in this class are self-explanatory. Each GenReg that takes part in the regulating power market are registered and returned to the Simulator by the sub-processes of the RegulatingMarket class.

Then for each of the generators that are registered, their respective bids are also added to the model to be considered for the regulation process. It also takes care of the timeEvents i.e.to start the bidding process, to regulate power and to clear the prices to be initialised and to tell the RegulatingMarket to be activated for that time event.

3 The SpotMarket class here just creates a very simple spot market object in which the spot price for each of the balancing periods are made available as this is used in the price determination process of regulating power.

SpotMarket
-vPrices:Vector -iTradingPeriodsCount:int -iBalancingPeriodsCount:int
+SpotMarket +init:void +price:int

Table A-4: The SpotMarket class diagram

4 The SytemOperator class creates objects for providing the demand data both for real and planned operations required during up and down regulations. It also tells the Simulator whether the current balancing period is for up or down regulation. The volume of regulating power for up and down regulations are retrieved by their respective methods and returned to the Simulator for the regulating process. The methods UPPlanned, DOWNPlanned, UPReal and DOWNReal return to the Simulator the boolean expressions of true or false of how the regulations are planned for all of the balancing periods.

SystemOperator
-vVolumeUP:Vector -vVolumeDOWN:Vector -vUPPlaned:Vector -vDOWNPlaned:Vector -vUPReal:Vector -vDOWNReal:Vector -iTradingPeriodsCount:in -iBalancingPeriodsCount
+SystemOperator +init:void +volumeUP:int +volumeDOWN:int +UPPlaned:boolean +DOWNPlaned:boolean +UPReal:boolean +DOWNReal:boolean

Table A-5: The SystemOperator class diagram

5 The InputReader class reads the input from the input file and feeds the information to the corresponding objects of bid data, demand data, boolean expressions for up and down regulations. This also writes the output onto the screen and in the output file. The process of reading the input is done through identifying the tabs between the strings of the input data.

InputReader
-sInputFile:String -spotMarketMine:SpotMarket -systemOperatorMine:SystemOpe -regulatingMarketMine:Regulatin
+InputReader -readInputFromFile:void -output:void -getStringsBetweenTabs:String[]

Table A-6: The InputReader class diagram

6 The GenReg class is for all of the regulating generators that are bidding to participate in the regulating power market. This class first adds all of the regulating generators ($GENS_{REG}$) and then adds all of the bids for both up and down-regulation from each of these generators to the RegulatingMarket. A certain bid for a particular balancing period of a trading period is also retrieved using the method getBid() of this class.

GenReg
-vBids:Vect
+GenReg +addBid:vo +getBid:Bid

Table A-7: The GenReg class diagram

7 The Bid class creates a bid object so that the bids for up and down-regulation of all the balancing periods of a trading period to be collected by the RegulatingMarket.

Bid
+tp:int +bp:int +volUP:int +priceUP:int +volDOWN:int +priceDOWN:i
+Bid

Table A-8: The Bid class diagram

8 The TimeEventSource class is

is first set using the calendar class.The events related to time are activated depending upon the clock. The time of the clock in this model has been scaled down to increase the speed of calculation and not to wait until the event has been activated. The clock first sets the starting time of the regulation process, scales it down by a value and returns it back to the model for the calculations. The TimeEventSource then adds to the model the time events, register a TimeEventListener for each of them, checks all the events to be activated and finally activates them if they are on time.

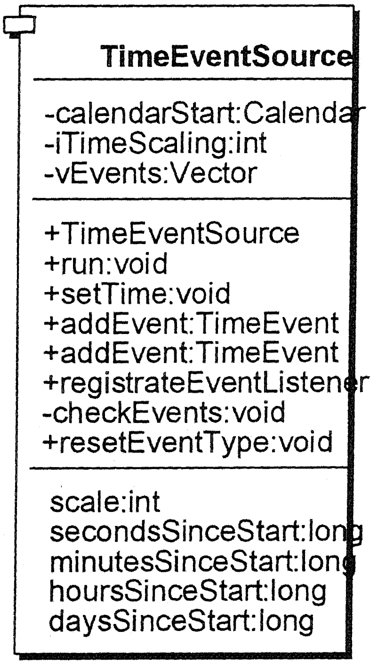


Table A-9: The TimeEventSource class diagram

9 The PriceModel class is an abstract class. This means although the methods of the PriceModel classes are same, the pricing mechanism for each of the power markets namely Norway, Sweden and Finland are different. The methods utilised are the calculation of regulation prices, allocation of volume to generators, ordering the generators to be activated based upon their bid prices and finally to calculate the results for the respective trading periods. The data from the generators are then returned back to the RegulatingMarket regarding whether they are selected for up or down regulation. The operations mentione in this class are self-explanatory and hence need no description.

PriceModel
#vGenRegSelUP:Vector #vGenVolUP:Vector #vGenRegSelDOWN:Vector #vGenVolDOWN:Vector #vGenPriceUP:Vector #vGenPriceDOWN:Vector
+PriceModel +calculateResForTB:void *+calculatePricesForTB:void* +allocateVolumeToGen:void +orderGenAccordinToPrice:Vector +getResultsForGenReg:Vector -correctPricesAccordingToVolume:v

Table A-10: The PriceModel class diagram

APPENDIX-3

1.3 TERMINOLOGY

1 **Balancing Group (BG):** A balancing group consists of an arbitrary number of injection and/or withdrawal points (usually metering points for generating units or power stations, and loads) within a control area, which have to be made known to the system operator responsible for the supply connection and which are thus exactly defined. A balancing group can also be established for the purpose of schedule administration only (e.g. power exchange balancing group).

2 **Balance management:** Operation through which a party of electricity trading aims to settle and influence, in advance or during the hour of use, how its electricity balance will be formed in a certain hour of use.

3 **Balancing Mechanism (BM) unit:** BM is a plant and apparatus which exports electricity to, or imports electricity from, the transmission grid. The minimum capacity for a Balancing Mechanism unit to be automatically considered is 50 MW.

4 **Balance provider:** A party of the electricity market who balances the difference between its power generation/procurement and consumption/deliveries through balance power trading with.

5 **Balance provider of the network:** The balance provider of an open supplier of the network. If the balance provider of the network is also an open supplier of the network, the balance provider of the network is the balance provider itself.

6 **Balance responsibility:** Responsibility for the situation where the power generation and power procurement agreements of a party of electricity trading cover its consumption and deliveries during each hour. All the parties of electricity trading have balance responsibility.

7 **Balance settlement:** Settlement of actual electricity generation, consumption and transactions, taking place after the hour of use. The power balance of each party of electricity trading is achieved as a result of the balance settlement.

8 **Bid:** A bid is a proposal to reduce generation or to increase consumption.

9 **Down-regulation:** Reduction in generation or increase in consumption.

10 **Down-regulation bid:** A bid given by a possessor of regulation resources to the regulation power market to reduce generation or increase consumption. When the bid is activated, the regulator purchases regulation power from System Operator.

downwards in the regulation power market during the particular hour becomes the down-regulation price. If no down-regulation has taken place during the hour, the price for price area in the power exchange becomes the down-regulation price.

12 **The Final Physical Notification (FPN):** It is a Balancing Mechanism unit's notified estimate at Gate Closure of its input/output for a particular trading period.

13 **Maximum Export Limit (MEL):** The maximum level at which the BM Unit may be exporting (in MW) to the NGC Transmission System at the Grid Entry Point or Grid Supply Point, as appropriate.

14 **Minutes reserve:** The minutes reserve is provided chiefly by thermal *power stations* operating under *secondary control*, and also by the deployment of storage stations, pumped-storage power stations, and gas turbines. Depending upon the size of the plant park, additional fast-start reserves may be required; the entire minutes reserve employed under *secondary control* and available for manual control must be at least as high as the power of the largest power unit, in order to permit sufficiently rapid compensation of frequency deviations in the event of failures.

15 **Nord Pool:** The Nordic power exchange which maintains three different markets:

ELBAS is a market place for physical electricity transactions after ELSPOT.

ELSPOT is a market place for physical electricity transactions during the following calendar day.

ELTERMIN is a market place for securing the price of electricity deliveries upto 3 years into the future. ELTERMIN's all products are financial products.

16 **Offer:** An offer is a proposal to increase generation or to reduce consumption.

17 **Physical notifications (PN):** It consists of an estimate of intended generation and demand of Balancing Mechanism units and may be revised at any time up to Gate Closure throughout the following trading day.

18 **Power Exchange:** A Power Exchange is a neutral marketplace with transparent pricing and equal conditions for all authorised participants. It does not pursue its own trade strategy.

19 **Power frequency characteristic (λ):** The power frequency characteristic (λ) defines the frequency behaviour of the complete interconnected system and of the control areas. The power frequency characteristic λ_u of the interconnected sys-tem is equal to the quotient of the power deficit (or surplus) ΔP_a causing the fault and the quasi-steady frequency deviation Δf which is caused by the fault.

20 **Primary control:** Primary control is the stabilising control, operating automatically in the seconds range, of active power of the complete, coupled, synchronously operated three-phase interconnected network. It is produced from the active contribution of the power stations to changes in system frequency, and is supported by the passive contribution of the loads which depend upon the system frequency (self-regulating effect).

21 **Primary control reserve:** The primary control reserve is the positive region of the primary control range from the operating point prior to the disturbance up to the maximum primary control power (in consideration of the limitation function). The term primary control reserve can be applied both to machines and to control areas and the interconnected system.

22 **Primary regulation:** Regulation supporting the system which takes place automatically when the frequency deviates from its nominal value.

23 **Regulation power or balance power:** As a result of a regulation request made by the System Operator, the electric energy relating to the power delivery between System Operator and the regulator.

24 **Regulation power market:** A market place in which all possessors of capacity which can be regulated can give bids on their free regulation capacity for both up-regulation and down-regulation.

25 Reserve system capacity: System capacity for supplying reserve power due to planned or unplanned power plant outages.

26 **Secondary control:** Secondary control is the influencing, in relation to a specific area, of generating units within a supply system for the purpose of maintaining the desired energy ex-change of the control area with the rest of the interconnected system whilst at the same time providing integral frequency back-up control. In the Union for the Co-ordination of Transmission of Electricity (UCTE), secondary control is achieved by means of power frequency control. in both directions from the operating point of the secondary control power (instantaneous value).

27 System users: These are customers who extract power, power stations and where applicable also traders.

28 **Secondary control reserve:** The secondary control reserve is the positive region of the secondary control band from the operating point up to the maximum value of the secondary control band. The range of the secondary control band, which has already taken

effect at the operating point, is termed the secondary control power. Range of the secondary control band, which has already taken effect at the operating point, is termed the secondary control power.

29 **Secondary regulation:** Manual up-regulation or down-regulation, which can be implemented by the party's own, need or request.

30 **System operator:** A system operator (operator of a transmission or distribution sys-tem) is responsible for secure and reliable operation of the network in question in a specific area and for connections to other networks. In addition, the operator of a transmission system controls power transfer across the network taking account of interchange with other transmission systems. He ensures the provision of essential system services and thus assures service reliability.

31 **System plant margin:** The system plant margin for each half-hour period is calculated by subtracting the identified BM Unit requirement from $\sum$MEL (after accounting for BM Units likely to be restricted by constraints).

System plant margin = ($\sum$MEL - $\sum$ Constrained Off BM Units) – BM Unit Requirement

32 **Spot price:** Price determined in the spot market (ELSPOT) of Nord Pool. There may be several spot prices in a market area, depending on the transmission capacity of the grid.

33 **System price:** Price determined for example in the ELSPOT market of Nord Pool, in which the physical transmission ability of the grid is not taken into account. The price is determined on the basis of all purchase and sales bids made in the ELSPOT market.

34 **Transmission system operator (TSO):** A TSO is operator of a transmission system.

35 **Up-regulation:** Increase in generation or reduction in consumption.

36 **Up-regulation bid:** A bid given by the party implementing the regulation to the regulation power market to increase generation or reduce consumption. When the bid is activated, the regulator sells regulation power to the regulation market.

37 **Up-regulation price:** The price of the most expensive regulation step, which regulates upwards in the regulation power market during the hour in question, becomes the up-regulation price. If no up-regulation has taken place during the hour, the price for price area in power exchange becomes the up-regulation price.

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